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Canada Cement Lafarge Ltd.

Energy Conservation in the Industrial Minerals Processing Sector Comminution (Crushing and Grinding) Phase III

Activity 4

Monitoring and Control of a Dry Grinding Circuit Using a Particle Size Analyser and Programmable Controllers

WITTECK DEVELOPMENT INC.

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PHASE III

ACTIVITY 4

Monitoring and Control of a Dry Grinding Circuit using a Particle Size Analyser and Programmable Controllers

ACTIVITY 4
MONITORING AND CONTROL OF A DRY GRINDING CIRCUIT USING A PARTICLE SIZE ANALYZER AND PROGRAMMABLE CONTROLLERS

ENERGY CONSERVATION
IN THE INDUSTRIAL MINERALS SECTOR
COMMINUTION - PHASE III
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1.0 EXECUTIVE SUMMARY

This work forms part of Phase III of the study on "Energy Conservation in the Industrial Minerals sector Comminution for Canada Centre for Minerals and Energy Technology (CANMET), Energy Mines and Resources Canada (EMR).

Phase I of the programme provided a data base of the direct energy consumed during the comminution of ten industrial minerals. Phase II provided a review of an on-stream particle size analyzer. Phase III of the programme is divided into various activities, of which Witteck Development Inc. and IMD Laboratories are responsible for Activities 1, 2, 3, 4, 6 and 7. This particular report covers Activity 4, Monitoring and Control of a Dry Grinding Circuit using a particle size analyzer and programmable controllers. The objectives for this activity included the following:

- Obtain baseline data for the milling circuit using a high efficiency classifier.
- Complete off-line testing of the particle size analyzer in both the wet and dry modes.
- Develop data to evaluate the operating characteristics, accuracy and repeatability of the particle size analyzer.
- Operate the milling/classification circuit with off-line monitoring of particle size analysis.
- Adjust classifier conditions and mill feed rate manually.

- Develop computer software to control milling circuit based on data from particle size analyzer.

- Control milling circuit using particle size analysis and a personal computer.

- Monitor and control production rates while milling circuit is in operation.

1.1 Procedures

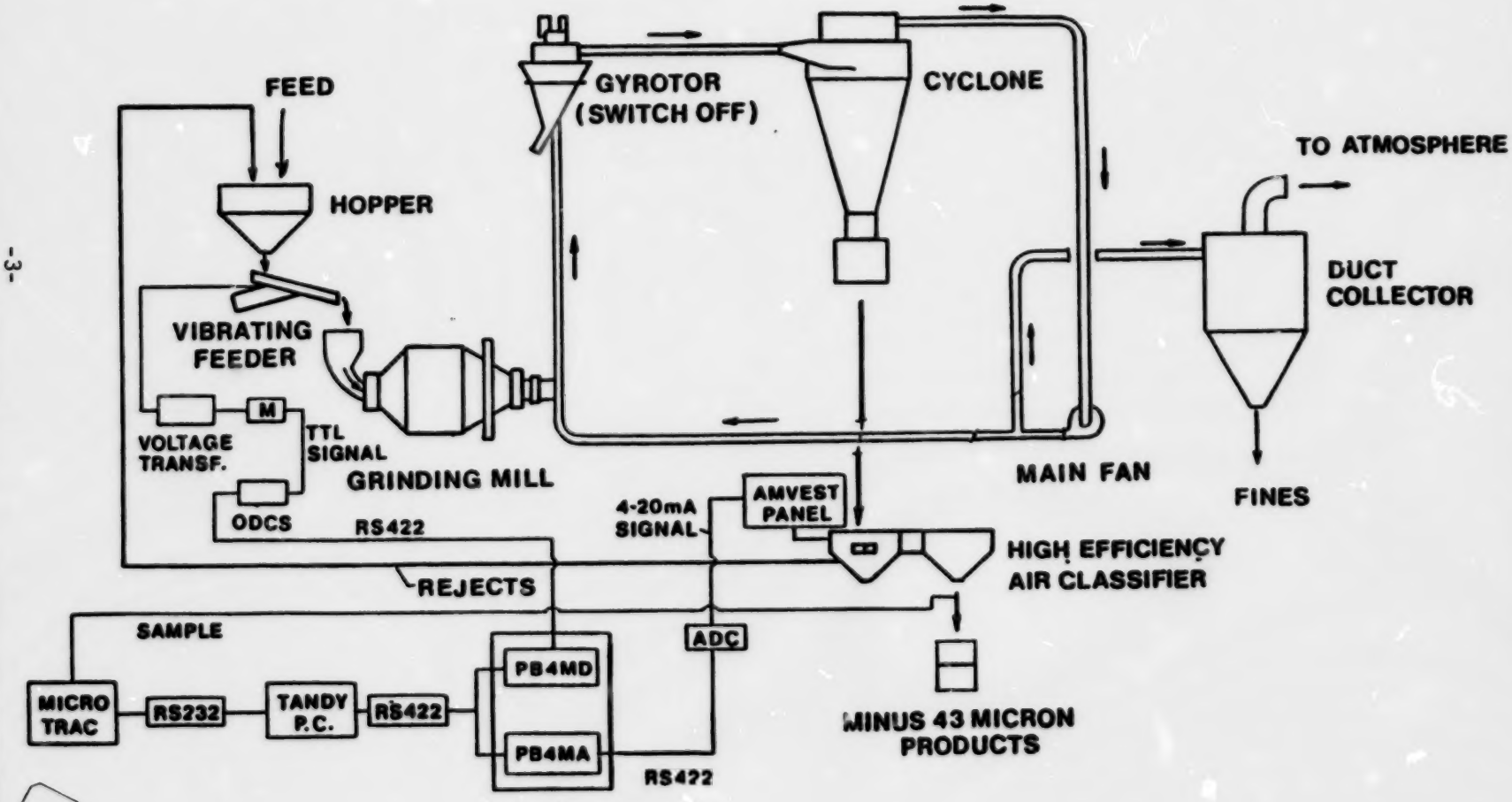
The tests were performed in a pilot plant comprised of a grinding mill, conventional classifier (not operating), cyclone collector, MS-5 high efficiency classifier, computer and logic controllers, Microtrac Particle Size Analyzer, and ancillary equipment such as a fan and dust collector. The circuit was operated as illustrated in Figure 1.1-F1.

Preliminary testwork with the Microtrac particle size analyzer in the dry mode indicated that size analysis of the Steep Rock calcium carbonate was unreliable due to particle agglomeration and erratic feed of the sample into the measuring cell. The particle size analyzer was operated in the wet mode. Discrepancies between the Microtrac and the Sedigraph particle size analyses were discovered. These discrepancies were caused by the double refractive index of the calcium carbonate. A statistical relationship between the Microtrac analysis and Sedigraph analysis was determined which alleviated this problem.

The classifier performance and efficiency were affected by the size and rate of material fed to the classifier. Product size was controlled by controlling the feed rate to the classifier as well as by adjusting the rotor speed to change the cut size of the product.

Figure 1.1-F1

GRINDING/CLASSIFICATION CIRCUIT



The computer software was developed to accept information including mill feed rate and particle size analysis of the classifier product. This information was processed by the computer and instructions were sent to the feeder and MS-5 classifier via logic controllers.

Twelve tests were completed averaging 3 to 5 hours in duration. The objectives of these tests were:

- o Maximize throughput while maintaining target product size.
- o Minimize product size fluctuations.
- o Improve recovery time for circuit to re-establish itself after an upset.

Sampling of the circuit product was taken manually and slurried for wet mode analyses by the Microtrac. Feed rates were set by the computer operator, based on classifier product and reject weights taken every six minutes.

1.2 Results

Figure 1.2-F1 illustrates the improvement in product size fluctuation that occurred when the circuit was under full computer control. Product size was measured by Mictrotrac analyser on product samples collected every 6 minutes. The data shows the D90, D50 and D10 per cent passing of the product plotted against time. The grinding classification circuit was controlled manually from 0 to 160 minutes. The computer controlled the circuit after 160 minutes. The computer control resulted in an increased amount of "on-spec" material produced for a given amount of energy consumption.

Figures 1.2-F2 and 1.2-F3 showed the ability of the computer controlled circuit to re-establish itself after a circuit upset, which was initiated after 100 minutes of operation. The circuit was restarted at 115 minutes as shown in Figure 1.2-F3.

Figures 1.2-F4 and 1.2-F5 showed the ability of a computer controlled circuit to maintain product specification, as throughput was steadily increased. This reduced production of off-spec material may result in substantial operating cost savings.

1.3 Conclusions

Based on pilot plant testing completed during Activity 4, the following conclusions have been determined:

1. On-line particle size analysis and computer control of the grinding and classification circuit was beneficial to the operation for the following reasons:

    - o Decrease operator input with circuit control being automatically implemented every six minutes.
    - o Maintained a constant product size distribution.
    - o Potential of increased production rate as a result of decreased production of off-spec product.
    - o Potential of decreased operating costs per tonne of product.

2. On-line particle size analysis was useful to a mill operator in monitoring and controlling the performance of the grinding and classification circuit.

   - The circuit was readily controlled to a given set point size represented by the D_{90} passing size.
   - After upsets or shutdowns, the circuit rapidly resumed its normal operation under computer control.
   - The circuit adjusted to a set point change in size of product required within twenty minutes.
   - Monitoring of the circulating load was important in the circuit because of the lag time between size set point changes and the stabilizing of the circulating load.

3. The Microtrac particle size analyzer is suitable for wet analysis of Steep Rock Calcium carbonate for the following reason:

   - Good repeatability of results in specific size ranges.
   - Accurate when correction factors are applied using a separate computer.
   - Rapid sampling and analysis time.
   - User friendly.

4. The Microtrac particle size analyzer is not suitable for dry analysis of Steep Rock Calcium carbonate for the following reasons:

   - o Steep Rock Calcium carbonate has a double refractive index.
   - o Particle agglomeration occurs when the sample is fed and transportated to the cell.

5. Pilot plant testing is important to properly assess the performance and efficiency of the comminution of a grinding circuit to produce an acceptable range of product sizes.

6. On-line particle size analysis and computer control of dry grinding and classification circuits has potential applications for reducing energy consumption per unit of product produced.

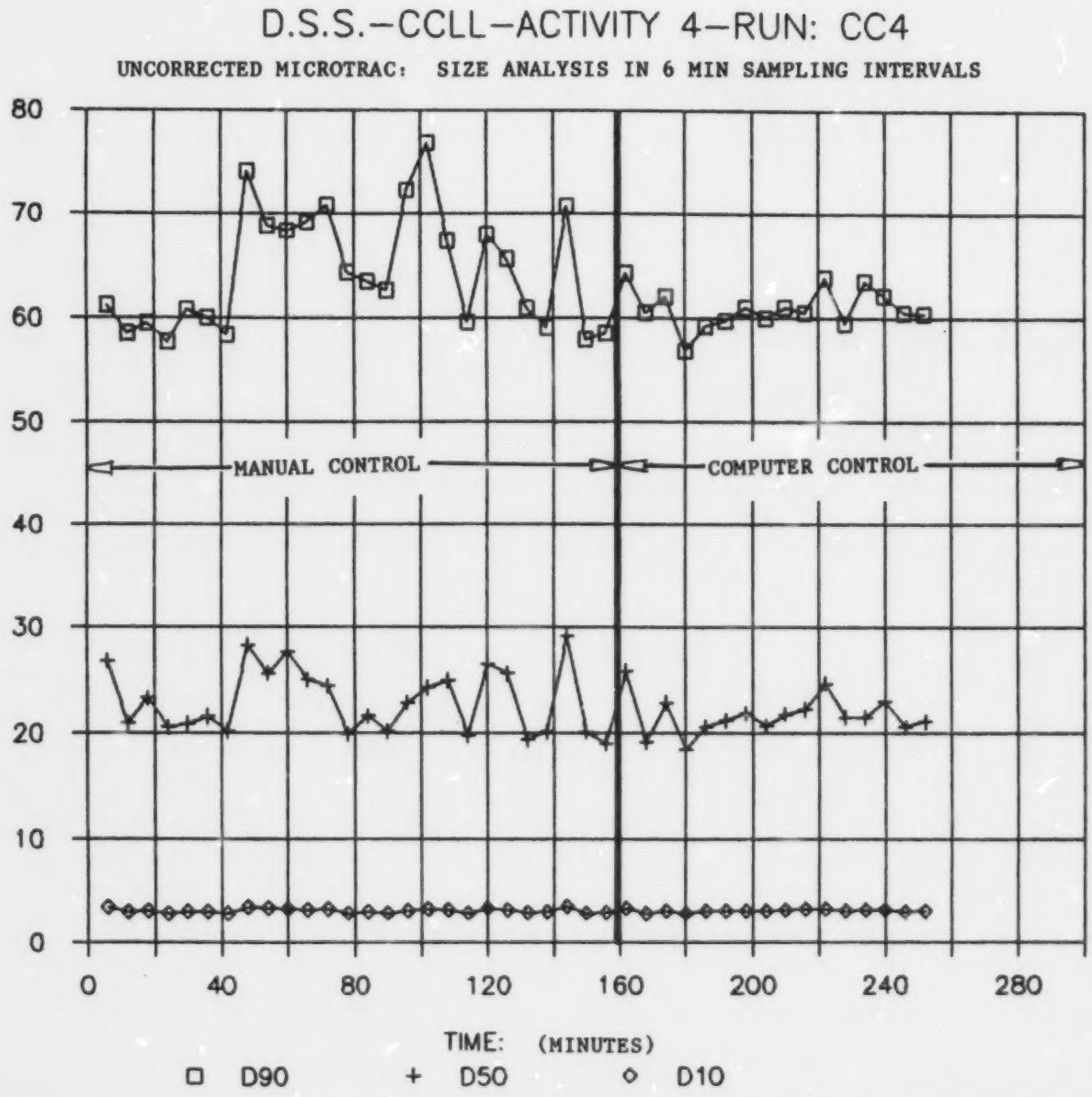

D.S.S.–CCLL–ACTIVITY 4–RUN: CC4
UNCORRECTED MICROTRAC: SIZE ANALYSIS IN 6 MIN SAMPLING INTERVALS
PRODUCT
PARTICLE SIZE (MICRONS)
80
70
60
50
40
30
20
10
0
MANUAL CONTROL
COMPUTER CONTROL
0
40
80
120
160
200
240
280
TIME: (MINUTES)
D90
D50
D10

Figure 1.2.F1

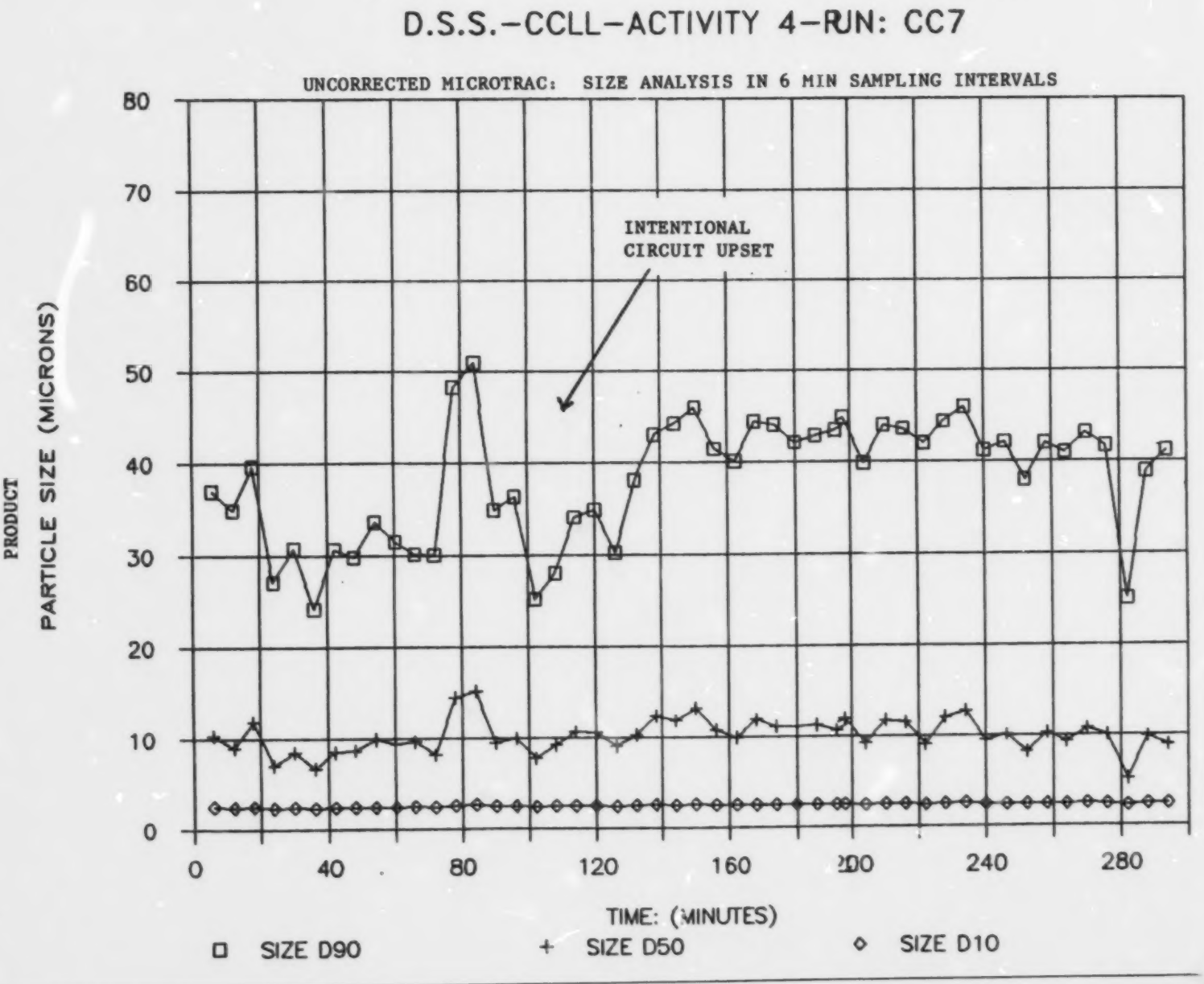

D.S.S.-CCLL-ACTIVITY 4-RUN: CC7
UNCORRECTED MICROTRAC: SIZE ANALYSIS IN 6 MIN SAMPLING INTERVALS
PRODUCT
PARTICLE SIZE (MICRONS)
INTENTIONAL
CIRCUIT UPSET
80
70
60
50
40
30
20
10
0
0
40
80
120
160
200
240
280
TIME: (MINUTES)
SIZE D90
SIZE D50
SIZE D10

Figure 1.2-F2

Figure 1.2-F3

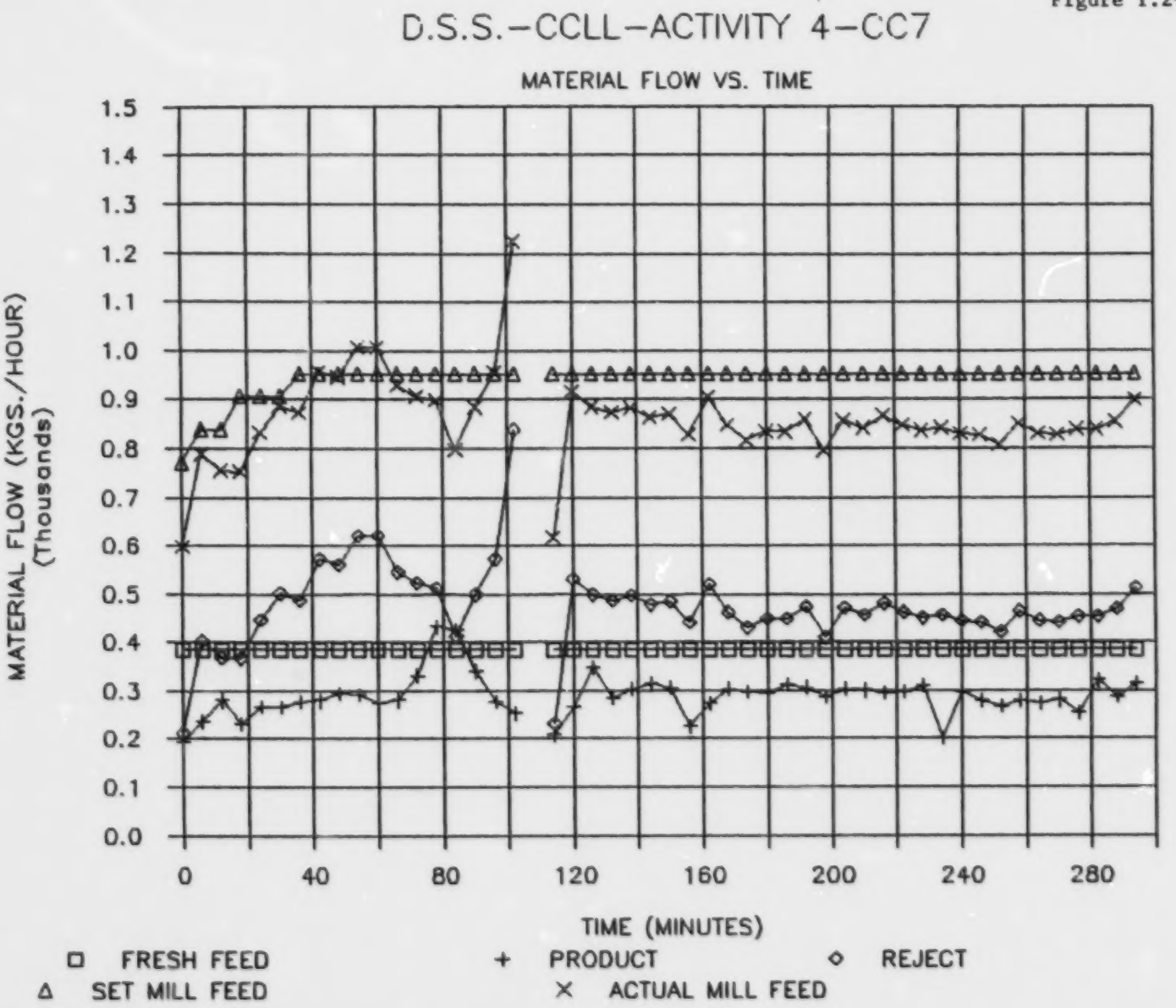
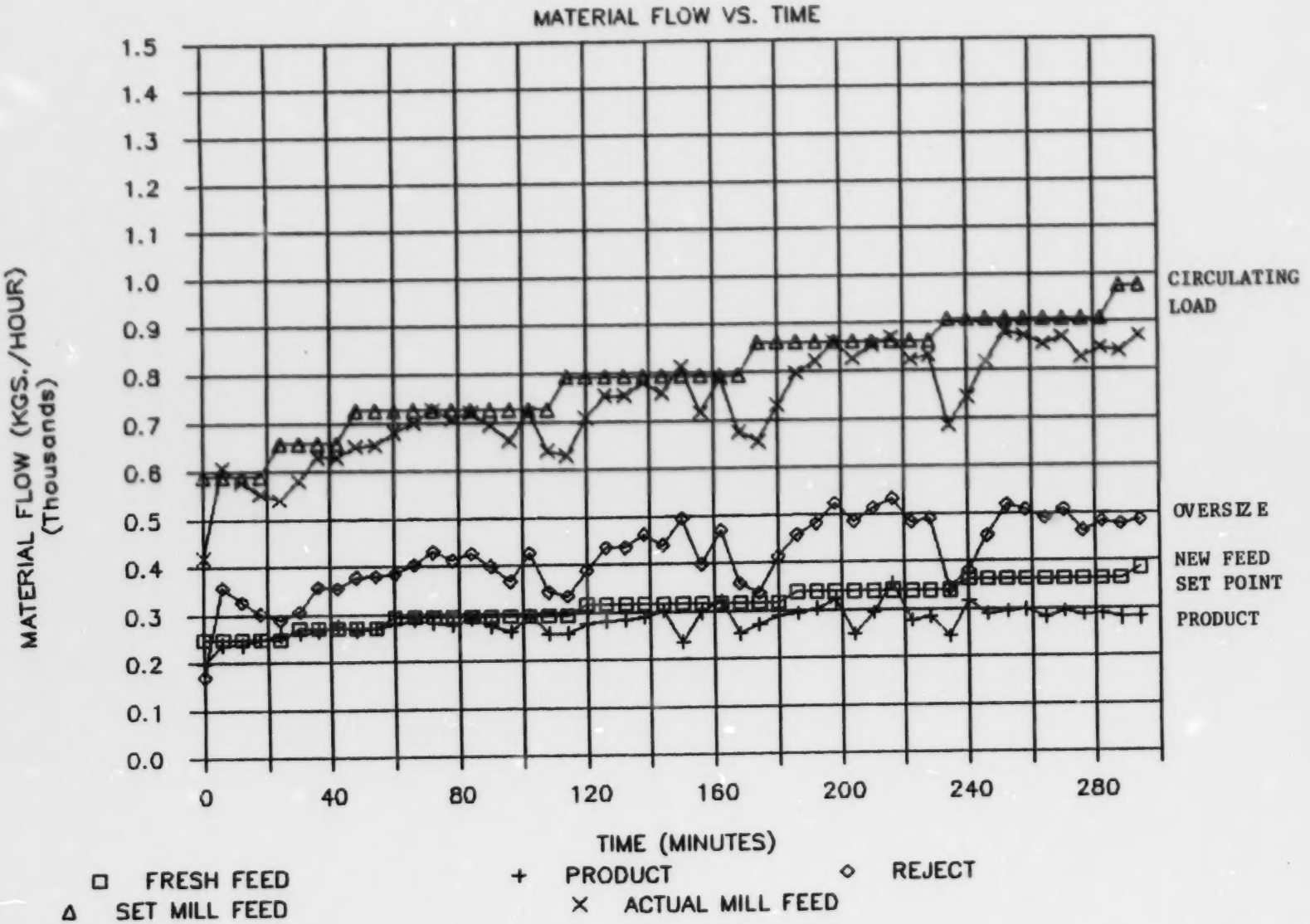

D.S.S.–CCLL–ACTIVITY 4–CC7
MATERIAL FLOW VS. TIME
MATERIAL FLOW (KGS./HOUR)
(Thousands)
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
40
80
120
160
200
240
280
TIME (MINUTES)
FRESH FEED
PRODUCT
REJECT
SET MILL FEED
ACTUAL MILL FEED

Figure 1.2-F4

D.S.S.-CCLL-ACTIVITY 4-CC9



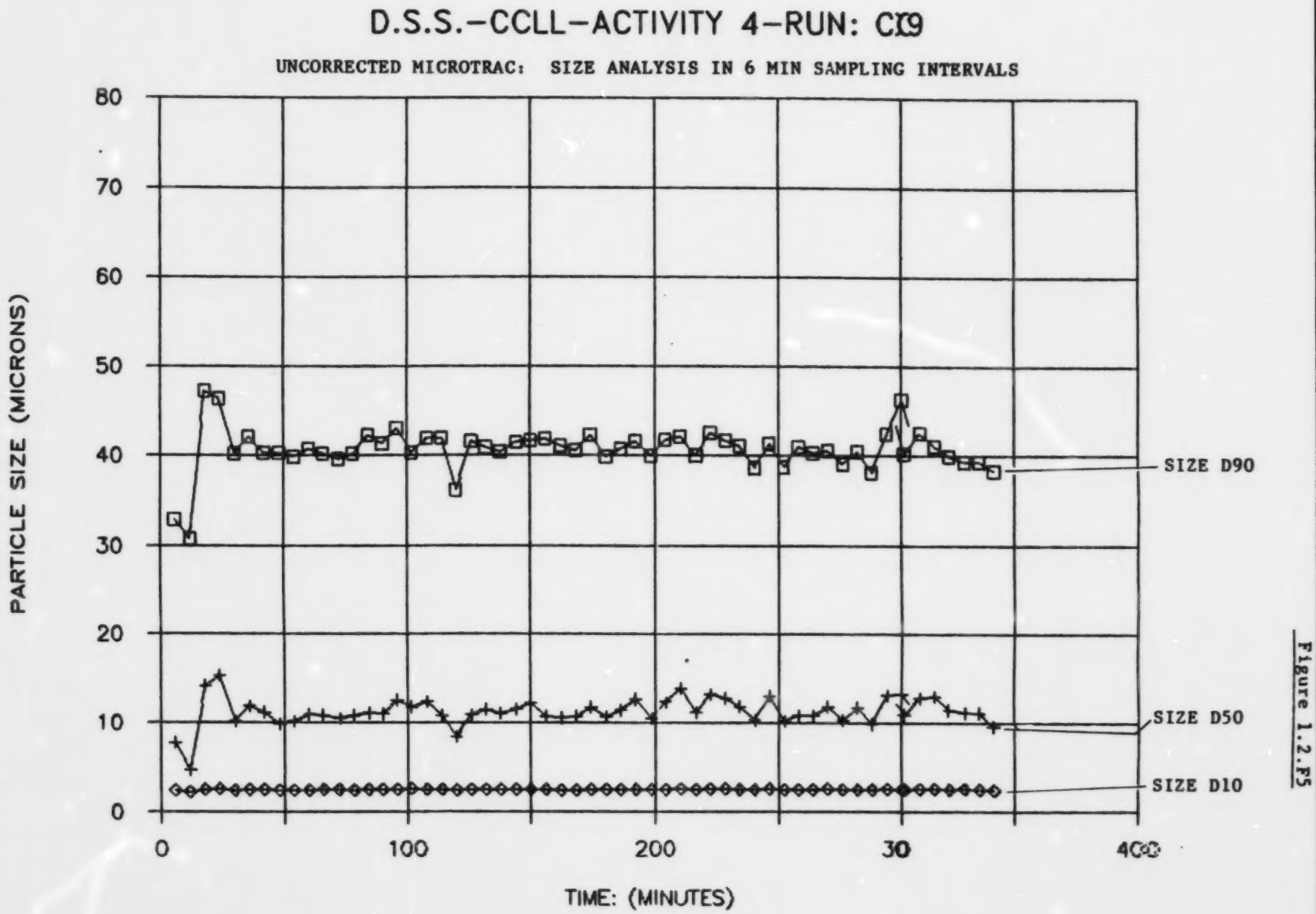

D.S.S.-CCLL-ACTIVITY 4-RUN: CX9
UNCORRECTED MICROTRAC: SIZE ANALYSIS IN 6 MIN SAMPLING INTERVALS
PRODUCT
PARTICLE SIZE (MICRONS)
80
70
60
50
40
30
20
10
0
0
100
200
300
400
TIME: (MINUTES)
SIZE D90
SIZE D50
SIZE D10

Figure 1.2.F5

1.0 RESUME DU PROGRAMME DIRECTEUR

Le présent travail entre dans le cadre de la phase III de l'étude sur "la conservation de l'énergie dans le secteur de la pulvérisation des minéraux industriels" destinée au Centre canadien de la technologie des minéraux et de l'énergie (CANMET) qui relève du Ministère de l'énergie, des mines et des ressources.

La phase I du programme a aidé au développement d'une banque de données sur la consommation directe d'énergie pour la pulvérisation de dix minéraux industriels. La phase II a permis l'examen d'un analyseur granulométrique en marche. La phase III est divisée en plusieurs plans d'activités, au nombre desquels les Nos 1, 2, 3, 4, 6 et 7 ont été confiés à la société Witteck Development Inc. et aux laboratoire IMD. Le présent rapport concerne le plan No 4, soit la surveillance et le contrôle d'un circuit de broyage à sec au moyen d'un analyzeur granulométrique et d'appareils de contrôle programmables. Ce plan d'activités a pour but:

- o d'obtenir des données de base sur le circuit de broyage comportant un classificateur à rendement élevé;
- o de terminer les essais hors-circuit de l'analyseur granulométrique, tant en voie humide qu'en voie sèche;
- o de développer des données pour évaluer les caractéristiques de fonctionnement, la précision et la répétabilité de l'analyseur granolométrique;
- o de régler le régime du classificateur et le débit de l'alimentation du broyeur manuellement;
- o de mettre au point le logiciel de l'ordinateur afin de contrôler le circuit de broyage en fonction des données de l'analyseur granulométrique;

1.0 Résumé du programme directeur (suite)

- de contrôler le circuit de broyage à l'aide de l'analyse granulométrique et d'un ordinateur individuel;

- de surveiller et de contrôler les taux de production durant le broyage.

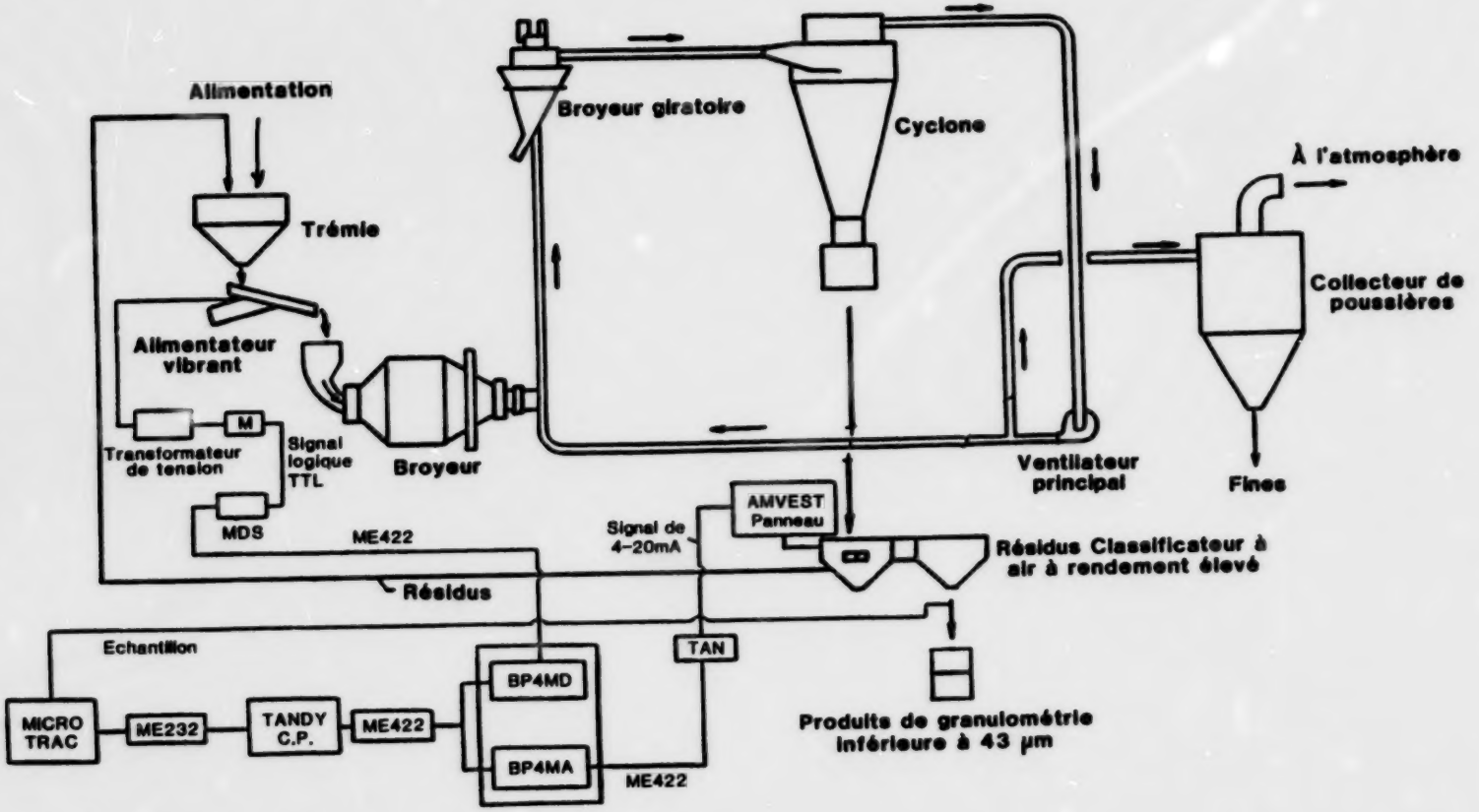
1.1 Méthodes

Les essais sont effectués dans une usine-pilote constituée: d'un broyeur, d'un classificateur conventionnel (non en service), d'un collecteur à cyclone, d'un classificateur MS-5 à rendement élevé, des contrôleurs d'ordinateur et de logiciel, d'un analyseur granulométrique Microtrac et d'équipement auxiliaire tel que ventilateur et collecteur de poussière. Le fonctionnement du circuit est représenté à la figure No 1.1-F1.

Le programme d'essais préliminaire réalisé avec l'analyseur granulométrique Microtrac en vois sèche indiquent que l'analyse du carbonate de calcium de "Steep Rock" est incertaine en raison de l'agglomération des particules et de l'alimentation irrégulière de l'échantillon dans la cellule de dosage. L'analyseur granulométrique fonctionne en voie humide. On a noté des écarts entre les analyseurs granulométriques Microtrac et Sedigraph. Elles sont dues à l'indice de réfraction double du carbonate de calcium. On a établi un rapport statistique entre les analyses Microtrac et Sedigraphe qui permet d'atténuer ce problème.

Le rendement et l'efficacité du classificateur sont influencés par la dimension et le taux d'alimentation du produit qu'il reçoit. La dimension du produit est contrôlée par le biais du taux d'alimentation du classificateur ainsi que le réglage de la vitesse du rotor qui permet de modifier la granulométrie du produit.

CIRCUIT DE BROYAGE ET CLASSIFICATION



1.1 Méthodes (suite)

Le logiciel de l'ordinateur est réglé de façon à recevoir des informations telles que: le taux d'alimentation du broyeur et l'analyse du produit du classificateur. Des informations sont traitées par l'ordinateur et les directives sont envoyées à l'alimentateur et au classificateur MS-5 par l'intermédiaire des contrôleurs logiques.

Douze essais, d'une durée moyenne de 3 à 5 heures, ont été réalisés. Les objectifs de ces tests étaient:

- o de maximiser la capacité tout en conservant la granulométrie;
- o de minimiser les écarts de granulométrie;
- o d'améliorer le temps de récupération nécessaire au rétablissement automatique du circuit après un refoulement.

Le prélèvement des échantillons se fait à la main avant d'en faire un coulis destiné à l'analyse par voie humide au Microtrac. Les taux d'alimentation sont réglés par l'opérateur de l'ordinateur en fonction du produit du classificateur et de la masse de résidus relevés toutes les six minutes.

1.2 Résultats

La figure 1.2-F1 représente l'amélioration des variations de la granulométrie lorsque le circuit est entièrement commandé par ordinateur. La granulométrie est mesurée par Microtrac sur des échantillons prélevés toutes les six minutes. Les données représentent le pourcentage de produit passant en fonction du temps, pour les dimensioms D90, D50 et D10. Le circuit de broyage et de classification est contrôlé manuellement de 0 à 160 minutes. L'ordinateur prend la relève du contrôle du circuit après 160 minutes. Le contrôle par ordinateur a permis une augmentation du volume du produit "spécifié" pour une quantité donnée de consommation d'énergie.

1.3 Conclusions

En se basant sur les résultats des essais réalisés en usine-pilote durant l'activité No 4, on est arrivé aux conclusions suivantes:

1. Le fait de relier l'analyse granulométrique au contrôle par ordinateur du circuit de broyage et de classification, donne de meilleurs résultats, pour les raisons suivantes:

   - o réduction du nombre des données d'entrée de l'opérateur, le contrôle du circuit étant déclanché automatiquement toutes les six minutes;
   - o distribution d'un produit de dimensions constantes;
   - o possibilité d'augmenter le taux de production, du fait de la production décroissante de matière "hors specifications";
   - o capacité de réduire les frais d'exploitation pour chaque tonne de produit.

2. L'introduction de l'analyse granulométrique dans le circuit permet à l'opérateur du broyeur de surveiller et de contrôler le rendement du circuit de broyage et de classification.

   - o le circuit est facile à contrôler à un point de réglage préétabli, représenté par la dimension D90 de particules passant;
   - o après un refoulement ou une interruption, le circuit reprend rapidement son fonctionnement normal sous l'impulsion du contrôle de l'ordinateur;
   - o Le circuit s'ajuste à un changement du point de consigne de la taille du produit désiré, en l'espace de vingt minutes;

1.3 Conclusions (suite)

- la surveillance de la charge circulante du circuit est importante, en raison du retard existant entre le changement points de consigne de la dimension, et la stabilisation de la charge circulante.

3. L'analyseur granulométrique Microtrac convient à l'analyse par voie humide du carbonate de calcium de "Steep Rock", pour les raisons suivantes:

   - bonne répétabilité des résultats dans des intervalles de dimensions déterminés;

   - précision lors de l'application de facteurs de correction au moyen d'un autre ordinateur;

   - rapidité de l'échantillonnage et de la période d'analyse;

   - système attrayant.

4. L'analyseur granulométrique Microtrac ne convient pas à l'analyse à sec du carbonate de calcium de "Steep Rock", pour les raisons suivantes:

   - ce carbonate de calcium possède un indice de réfraction double;

   - il se produit une agglomération des grains lors de l'alimentation et du transport de l'échantillon à la cellule.

5. L'essai en usine-pilote est important afin d'évaluer le rendement et l'efficacité de la pulvérisation d'un circuit de broyage pour la production d'une gamme convenable de particules.

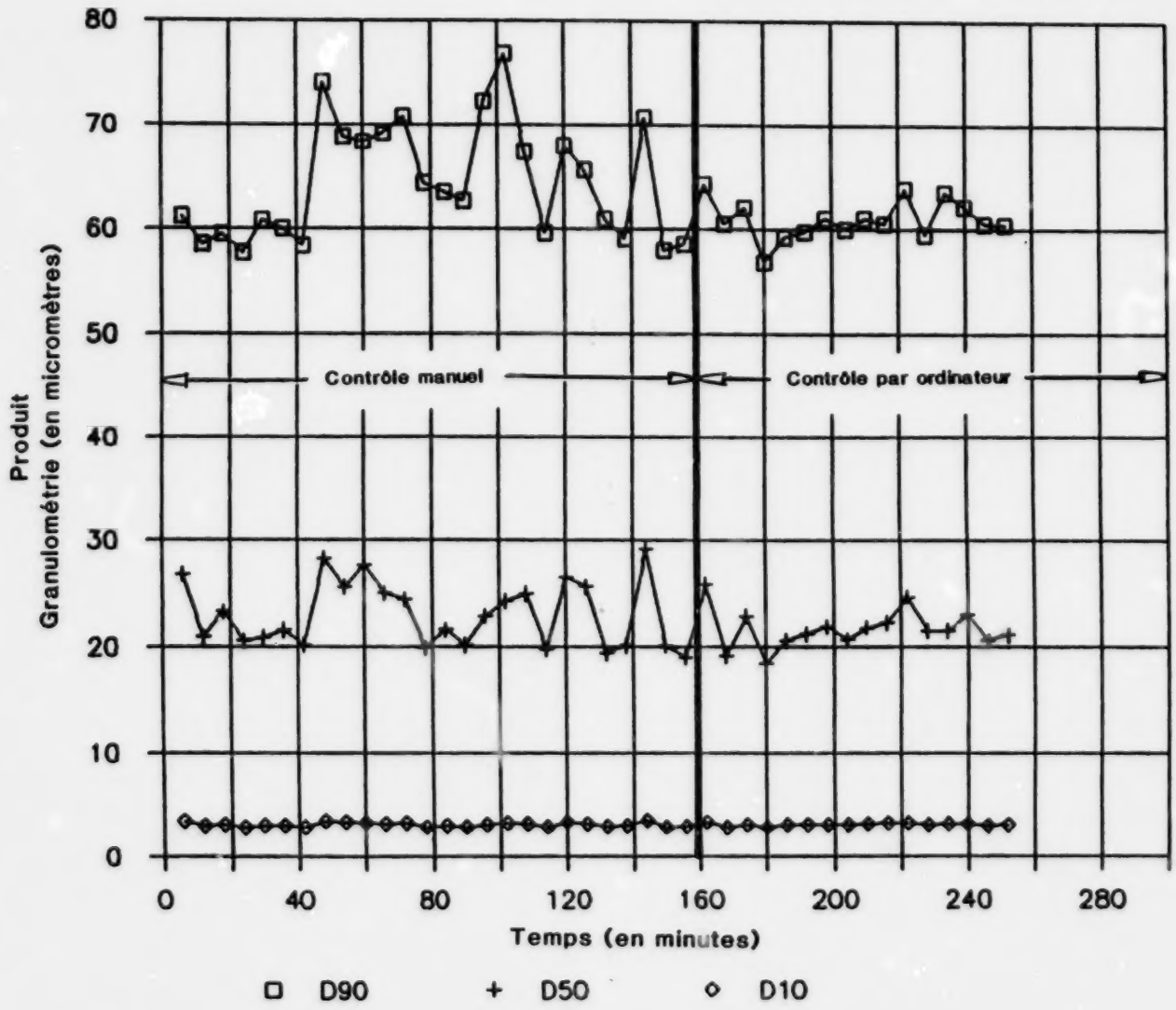
1.3 Conclusions (suite)

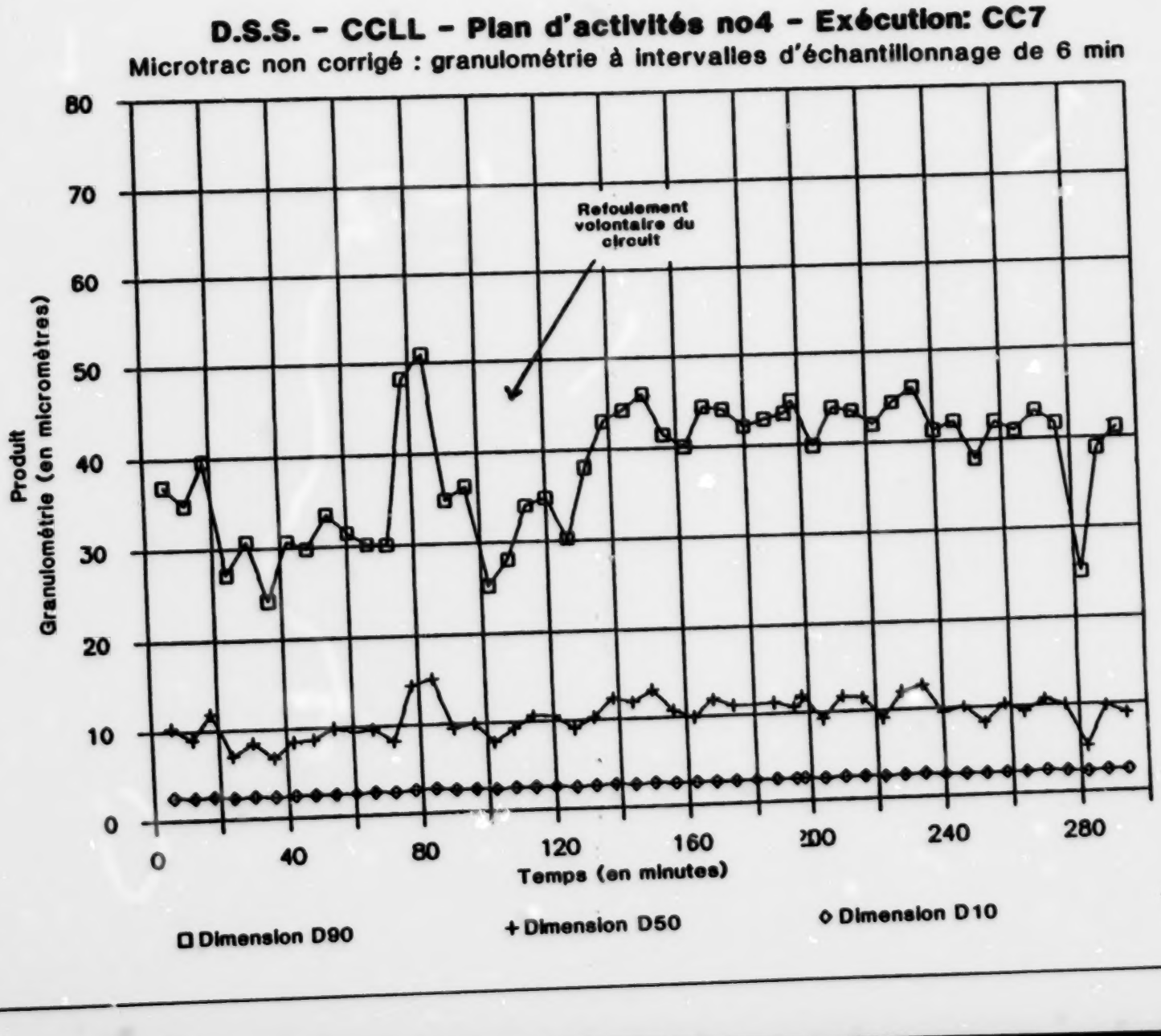
6. L'introduction de l'analyse granulométrique et du contrôle par ordinateur dans les circuits de broyage et de classifiaftion à sec permet d'envisager des applications qui sont susceptibles d'améliorer la consommation d'énergie par tonne de produit manufacturé.

Figure 1.2-F1

D.S.S. - CCLL - Plan d'activités no4 - Exécution: CC4

Microtrac non corrigé : granulométrie à intervalles d'échantillonnage de 6 min




D.S.S. - CCLL - Plan d'activités no4 - Exécution: CC7
Microtrac non corrigé : granulométrie à intervalles d'échantillonnage de 6 min
Produit
Granulométrie (en micromètres)
80
70
60
50
40
30
20
10
0
Refoulement volontaire du circuit
0
40
80
120
160
200
240
280
Temps (en minutes)
Dimension D90
Dimension D50
Dimension D10

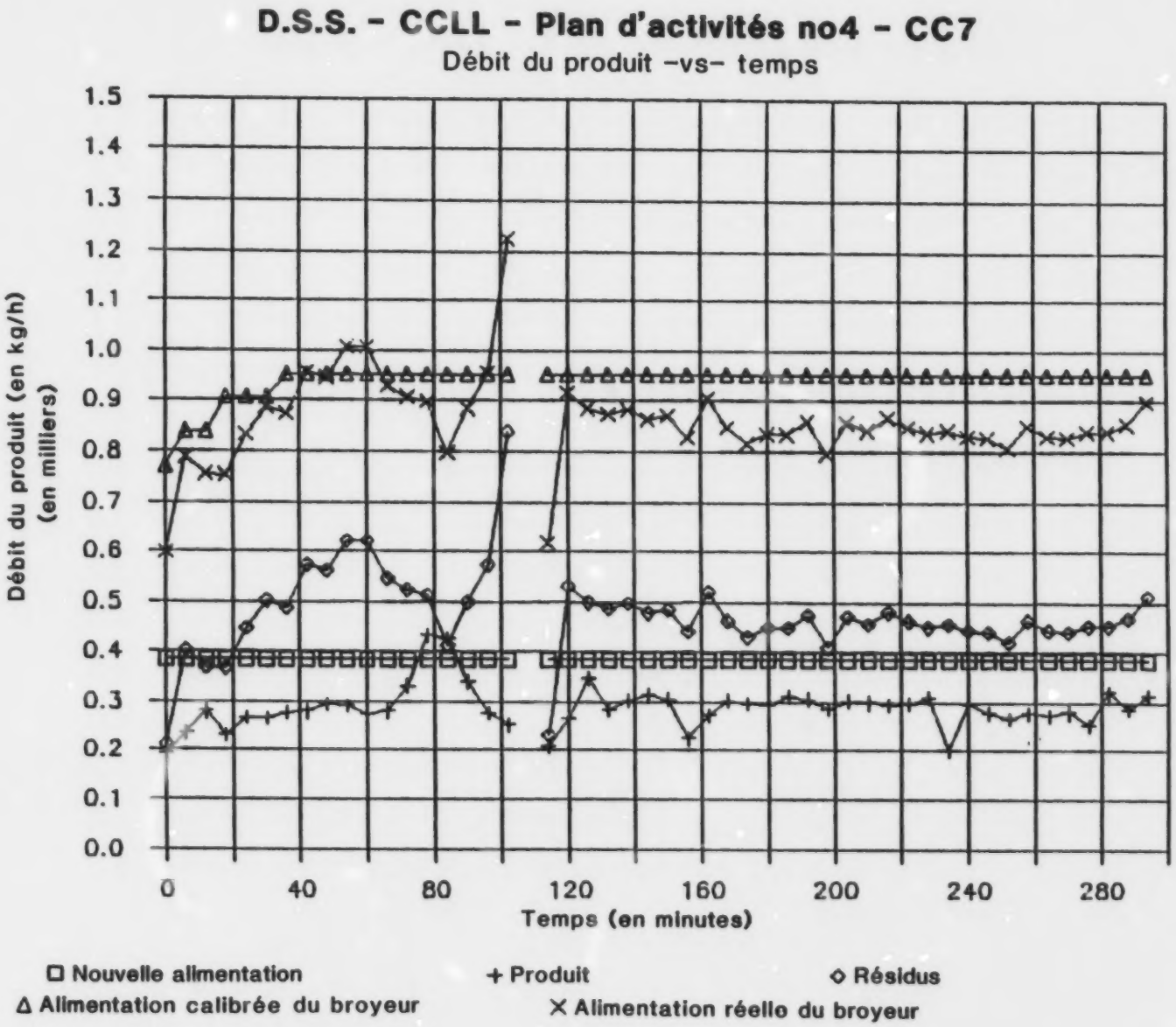
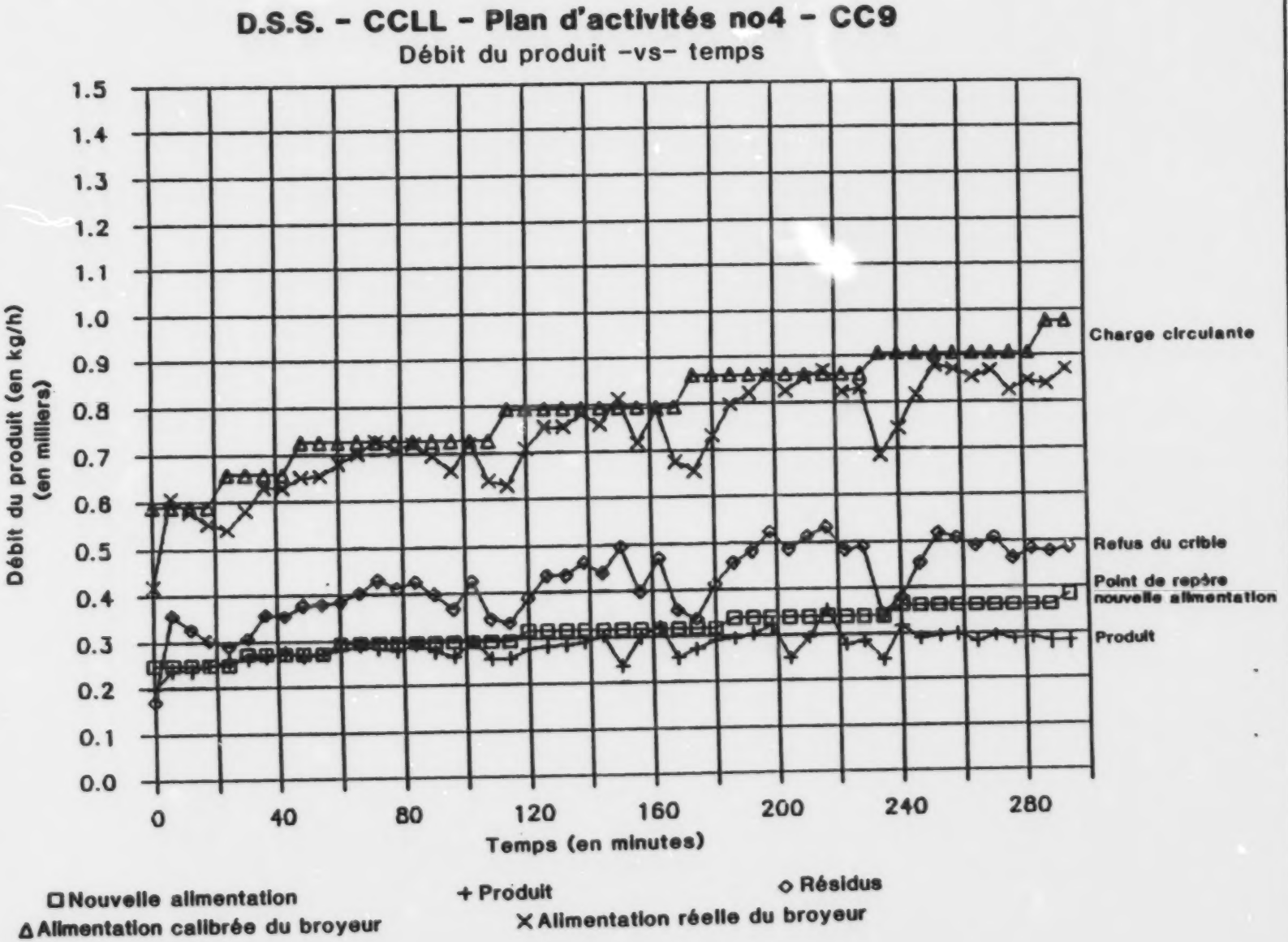
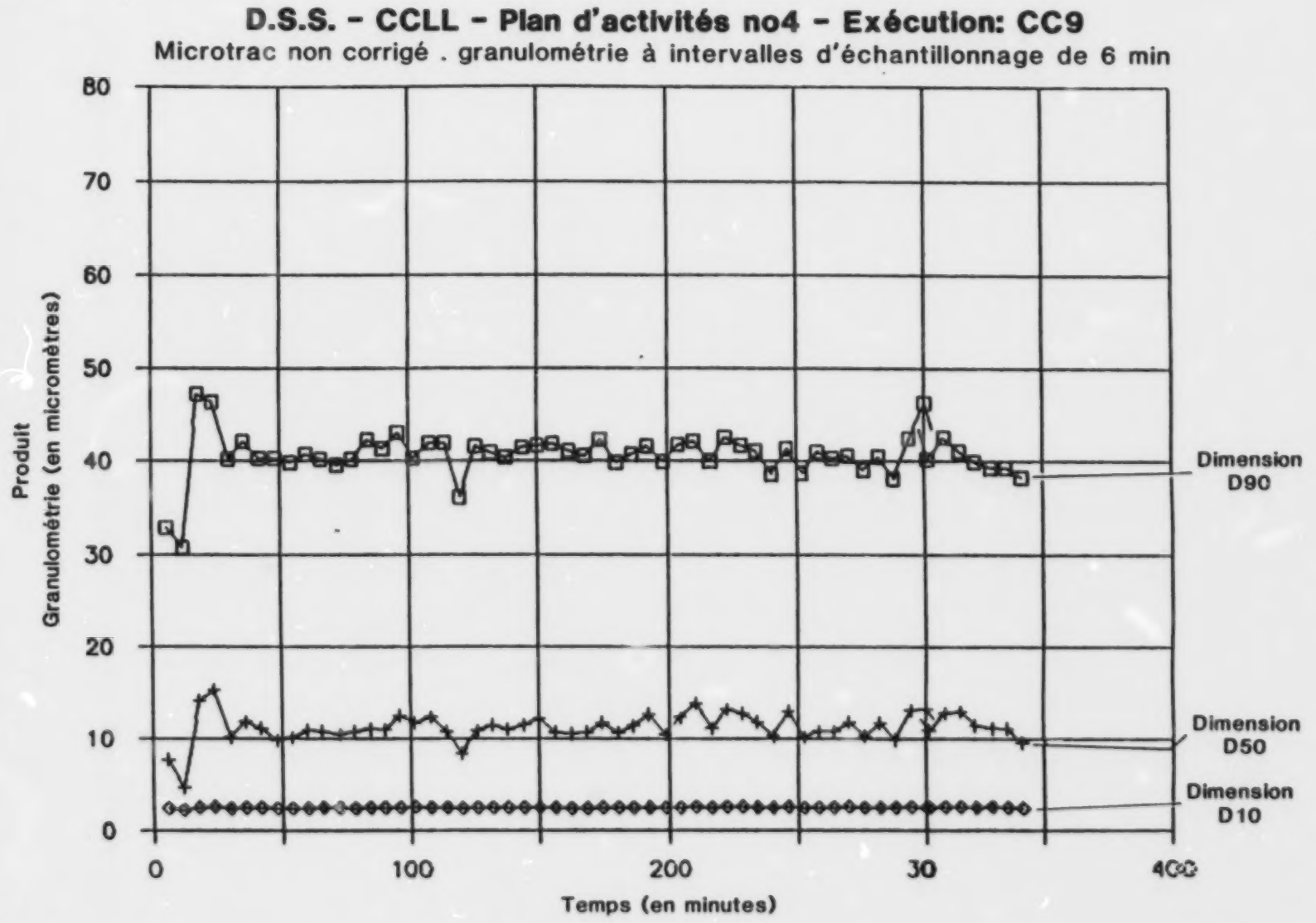

D.S.S. - CCLL - Plan d'activités no4 - CC7
Débit du produit -vs- temps
Débit du produit (en kg/h)
(en milliers)
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
40
80
120
160
200
240
280
Temps (en minutes)
□ Nouvelle alimentation
+ Produit
◇ Résidus
△ Alimentation calibrée du broyeur
× Alimentation réelle du broyeur

Figure 1.2-F4


D.S.S. - CCLL - Plan d'activités no4 - CC9
Débit du produit -vs- temps
Débit du produit (en kg/h)
(en milliers)
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
40
80
120
160
200
240
280
Temps (en minutes)
Charge circulante
Refus du crible
Point de repère nouvelle alimentation
Produit
□ Nouvelle alimentation
△ Alimentation calibrée du broyeur
+ Produit
◇ Résidus
× Alimentation réelle du broyeur


D.S.S. - CCLL - Plan d'activités no4 - Exécution: CC9
Microtrac non corrigé . granulométrie à intervalles d'échantillonnage de 6 min
Produit
Granulométrie (en micromètres)
80
70
60
50
40
30
20
10
0
0
100
200
300
400
Temps (en minutes)
Dimension D90
Dimension D50
Dimension D10

2.0 INTRODUCTION

The Canadian Industry Program for Energy Conservation (CIPEC) reported a 15% reduction in energy consumption per tonne of output in 1982, compared to the base year 1974. Much of this saving could be attributed to improved housekeeping. Achieving further conservation would require process modification and fuel switching; both require Research and Development (R&D). The areas for work were grouped as follows:

General R&D	-applicable to industrial mineral processing in general
Cement R&D	-processing of Portland and other hydraulic cements and gypsum plaster,
Clay products R&D	-applicable to manufacture of brick,tile pipe, etc.

The Department of Energy, Mines and Resources (EMR) CANMET, wishing to assist the industrial minerals processing sector in improving the energy efficiency of its operations, commissioned this study.

The overall objective as stated by EMR was:-

> To develop the necessary technology to optimize the comminution of industrial minerals in terms of direct and indirect energy consumption.

EMR defined direct and indirect energy consumption in the following way.

> Direct energy consumption measures the work done during the crushing and grinding operations and is expressed in kWh/tonne.
>
> The indirect energy consumption is less frequently recognized and harder to quantify. Its effects are felt during secondary processing or utilization of comminuted materials. The correct size distribution of cement for example could command savings of up to 10% of the amount of cement necessary to make concrete. Optimization of comminution both in terms of kWh/tonne and in terms of processing energy consumption would make a major contribution to energy conservation in the industrial minerals processing sector.

Ten industrial minerals were chosen for study and, to achieve the objective, the work was divided by EMR into three phases.

Phase 1 Plant Studies to Develop a Data Base.

> For each mineral, studies were made of power consumption during comminution at a plant whose operations are typical of the industry. The results are from a brief investigation of the company's operations and therefore, are descriptive rather than analytical.

Phase II Establishment of Monitoring Methodology

> An evaluation was made of commercially available particle size measuring equipment with a view to establishing the feasibility of mill circuit control by on-line particle size measurements.

Also under this phase, a proposal for a pilot plant test program was developed.

Phase III Pilot Plant Studies of Comminution Related to Industrial Minerals and Energy Consumption.

This report is presented in accordance with Phase III, Activity 4 of the study on "Energy Conservation in the Industrial Mineral Sector - Comminution" for Canada Centre for Mineral and Energy Technology (CANMET), Energy, Mines and Resources Canada (EMR).

Witteck Development Inc. of Mississauga, Ontario, and I.M.D. Laboratories Ltd. of Toronto, are responsible for Activities 1, 2, 3, 4, 6 and 7 of the Phase III programme. The Activities include the following:

Activity 1 Examination of the performance of a "state of the art" high efficiency classifier in a conventional milling circuit.

Activity 2 Examination, study and analysis of the state of development of classifiers for cement grinding circuits.

Activity 3 Examination of the use of grinding aids and anti-static agents in dry grinding circuits.

Activity 4 Monitoring and control of a dry grinding circuit using a particle size analyzer and programmable controllers.

Activity 6 Evaluation of the use of dry autogenous grinding of silica to produce coarse size sand grade product.

Activity 7 Development of the necessary technology to optimize the comminution of mica.

The objective of Activity 4 was to optimize circuit output in terms of product quality and productivity rate, using on-line control of circuit throughput and classifier operating conditions. This report presents the results of the pilot plant testing.

Tests were performed in the pilot plant using a dry grinding mill, conventional air-classifier (not operating), cyclone collector and high efficiency air classifier, plus ancillary equipment such as a fan and dust collector.

A Microtrac analyzer was used to measure particle size. This unit performed measuring and analytical functions and also transmitted electrical signals used by a computer to control mill feed and classifier operations.

Control of the circuit was achieved through the use of logic controllers which were programmed and operated using a personal computer.

3.0 DESCRIPTION OF EQUIPMENT

3.1 Conical Mill

The mill utilized for the pilot plant program was a 1220 mm diameter by 406 mm long Hardinge conical mill. The mill was not equipped with grating. The liners were manufactured from Ni-Hard steel. The discharge tube to the aspirator was 229 mm in diameter by 406 mm long. The mill bearings were babbitt type and were lubricated with block grease. The mill operated at 31 RPM or 81 percent of critical speed.

3.2 Cyclone Separator

A 1524 mm diameter cyclone was utilized to remove fines from the airstream during the test programme. The air flow rating of the cyclone is 57 cubic metres of air per minute at $20^{o}C$. A flop gate at the bottom of the cyclone allows removal of fines by gravity while maintaining an airtight seal.

3.3 High Efficiency Classifier

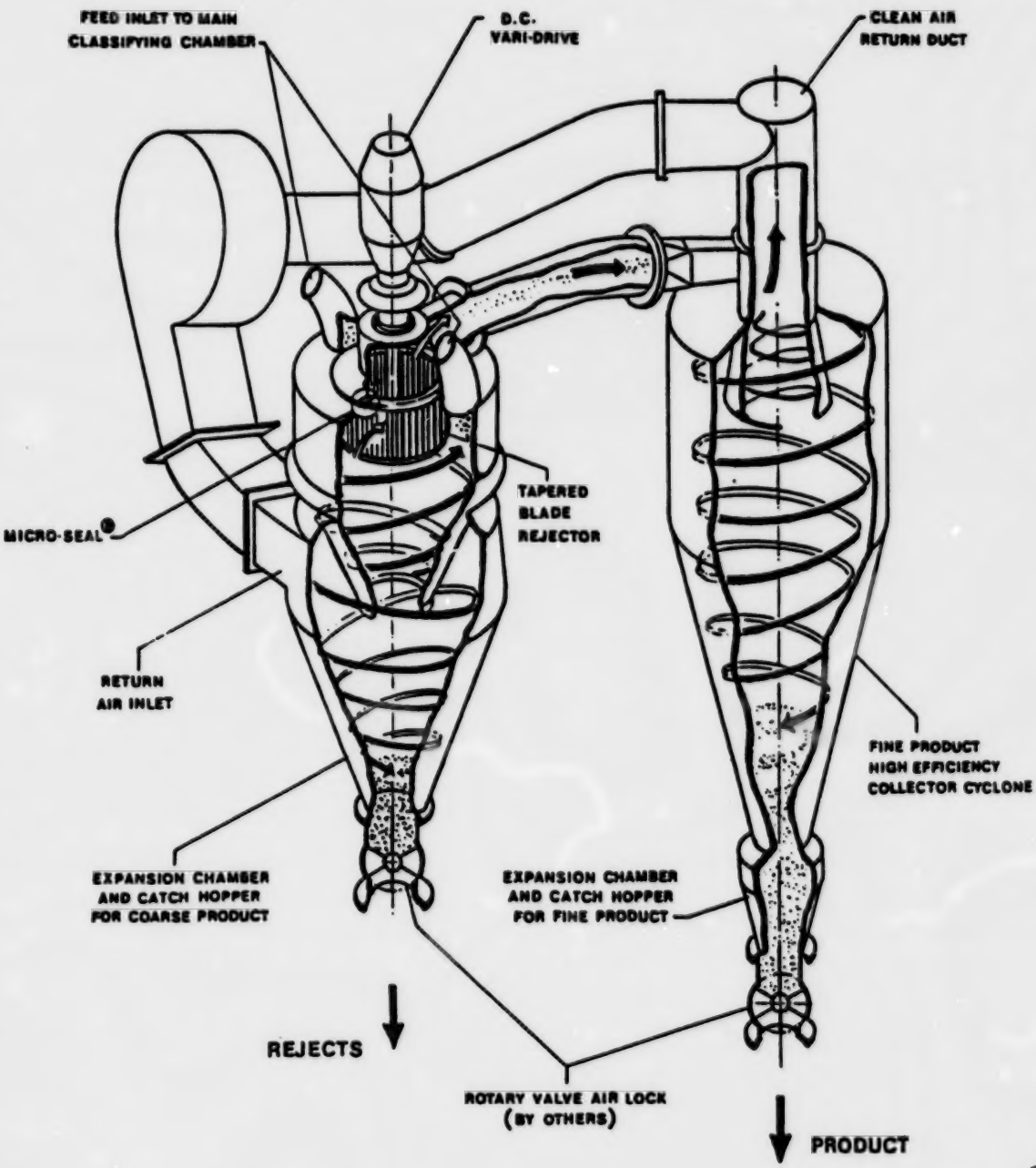
The high efficiency classifier utilized for the pilot plant was a Model MS-5 high efficiency classifier. The rented classifier system was a self-contained unit, complete with feed hopper, rotary air locks, system fan, collection cyclone, and control panel. The classifier is illustrated in Figure 3.3-F1.

3.4 Dust Collector

The dust collector utilized for this Activity was a Wheelabrator Model MPF-Pulse Dust Collector, size No. 33 with nine filter elements.

Figure 3.3-F1

AMVEST-MS 5 CLASSIFIER INSIDE THE MICRO-SIZER


FEED INLET TO MAIN CLASSIFYING CHAMBER
D.C. VARI-DRIVE
CLEAN AIR RETURN DUCT
TAPERED BLADE REJECTOR
MICRO-SEAL®
RETURN AIR INLET
FINE PRODUCT HIGH EFFICIENCY COLLECTOR CYCLONE
EXPANSION CHAMBER AND CATCH HOPPER FOR COARSE PRODUCT
EXPANSION CHAMBER AND CATCH HOPPER FOR FINE PRODUCT
REJECTS
ROTARY VALVE AIR LOCK (BY OTHERS)
PRODUCT

The filter elements were 330 mm in diameter by 660 mm long multi-pleated, polyester type filters of 176 ounces per square yard material. The unit was constructed of 12 gauge M.R.S. welded panels reinforced to withstand 380 mm W.G. pressure. The rated capacity of the dust collector was 2.1 cubic metres/sec at 20°C.

The elements are cleaned by a pulse of reverse flow of air through the filters. The filters are cleaned on a row by row basis, three at a time, allowing continuous operation of the dust collector.

3.5 Main Exhaust Fan

The main exhaust fan utilized for Activity 4 was a Buffalo Forge, Size 25 MW Centrifugal fan with straight paddle blades. The wheel diameter was 445 mm. The outer area was .052 square metres and the inlet area .057 square metres. The fan was equipped with an extra heavy duty shaft and roller bearings for high speed operation. Fan capacity is 1.6 cubic metres/sec at 432 mm W.G. and 20°C.

3.6 Microtrac Particle Size Analyzer

On-line measurements of particle size were performed with a Leeds & Northrup Microtrac, Model 7991-01 Particle Size Analyzer. The Microtrac provided analysis of particle size from 18 - 176 microns in either dry or slurry mixture. Measurement time ranged from 3 to 800 seconds, with 30 seconds being the typical time required. Data was presented by either a digital printer or RS232 output for remote processing.

3.7 Computer

The computer utilized for Activity 4 was a Tandy Model 1000 personal computer, with a 364K RAM memory and one 5 1/4" floppy disk drive. A 23 cm. black and white monitor was used for data presentation. Serial communications included RS232C for data input from the Microtrac Particle Size Analyzer and RS422 for output to the logic controllers.

3.8 Logic Controllers

Analog control to the high efficiency classifier was provided by a OPTOMUX, programmable controller. This controller consisted of PB4MA, Analog Mounting Board with capacity of 4 input or output modules. The board contained a microprocessor, which was programmed by a host computer, to signal the various modules. The analog module used to control the high efficiency classifier is a model DA3, 4 to 20 mA output module.

Digital control of the feeder was through a PB4MD Optomux Digital Mounting Board, complete with microprocessor and two ODS5, 0 - 5 volt output modules.

Both the analog and digital controllers, were mounted in an enclosed rack in a dust free computer room.

3.9 Computer Room

A 2.4 by 3.66 meter computer room was built for this activity. The room contained the Microtrac particle size analyzer, computer, an enclosed rack for the logic controllers and a variable step transformer to control the feeder.

The room was thoroughly sealed and kept under positive pressure to maintain a dust free atmosphere. Water was available for the Microtrac operation, as well as for sample preparation.

3.10 Sedigraph Particle Size Analyzer

The particle size analyzer used for Activity 4, was a Micrometrics Sedigraph Model 5000 E.T. This analyzer measured particle sizes from 0.1 to 100 microns with an accuracy of 1%, provided liquid and solid densities are known, and were at a proper temperature. Reproducibility was 1% for particles greater than 1 micron, 3% for particles between 0.5 to 1 micron and 5% for particles below 0.5 micron. Sedigraph results could be displayed as cumulative per cent retained, or cumulative percent passed.

4.0 TEST PROCEDURES

4.1 Circuit Description

A flowsheet of the circuit utilized for these tests is illustrated in Figure 4.1-F1.

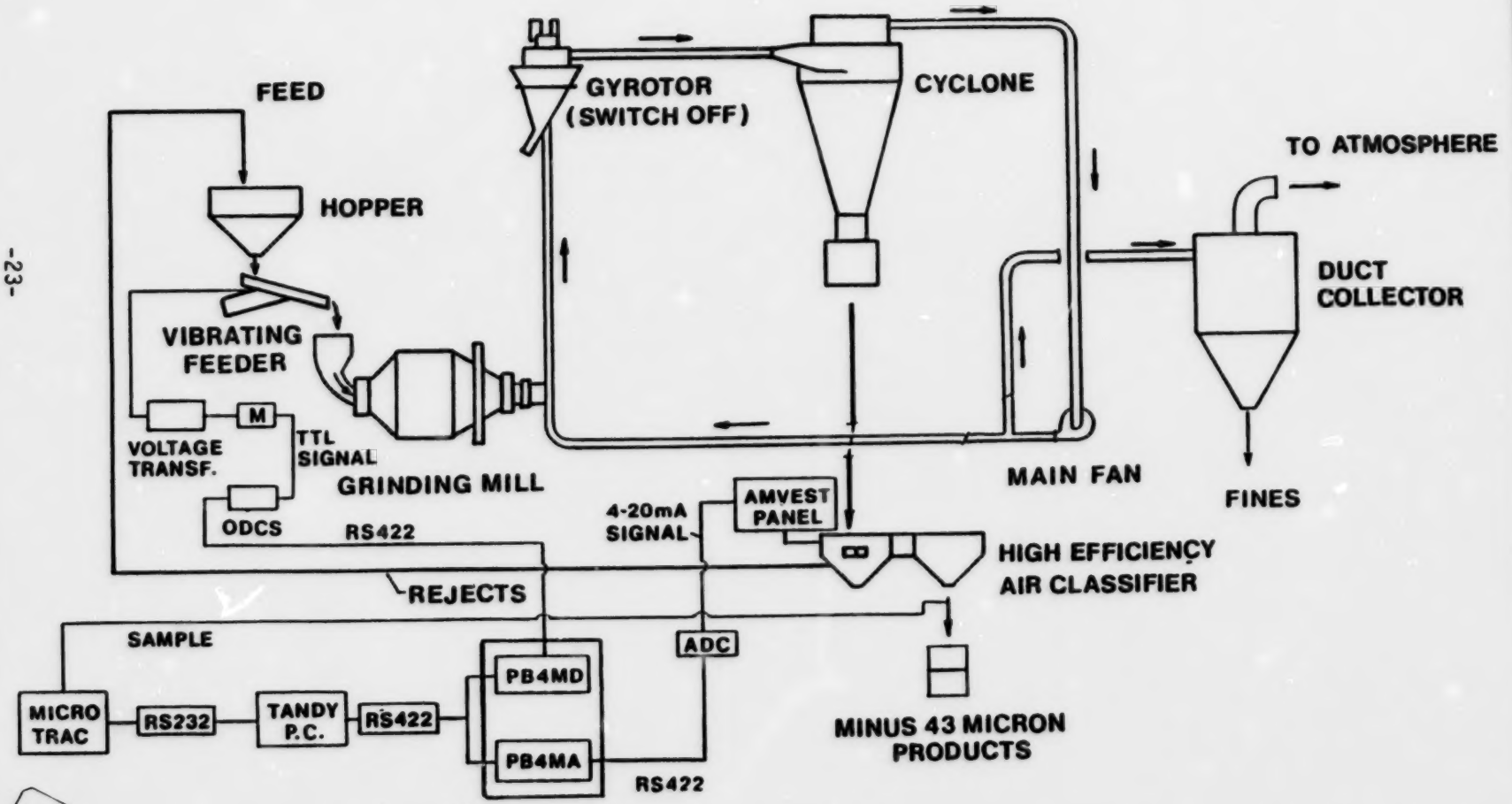
Product and oversize materials were collected manually from the high efficiency classifier using 20 litre buckets. The product and oversize materials were weighed at 6 minute intervals and the weights recorded. Hourly production and return rates could then be calculated by multiplying the recorded weights by 10. The product was transferred to 205 litre drums while the oversize was transferred to a front-end loader.

New feed, in pre-weighed buckets, was added to the oversize in the front end loader, which then transferred the combined material (feed and oversize) to the mill feed hopper. The feed hopper acted as a surge bin ensuring uniform flow to the mill, as well as allowing the feed and oversize to form a homogeneous mixture. The vibratory feeder to the mill was adjusted to feed the combined rate of new feed and oversize to the mill.

Samples collected manually from the high efficiency classifier were analyzed by the Microtrac which then fed the data to the computer. The computer using this data sent instructions to the logic controllers which adjusted the high efficiency classifier or vibratory feeder operating ratio.

Figure 4.1-F1

GRINDING/CLASSIFICATION CIRCUIT



4.2 Baseline Mill Runs

The purpose of the base line mill runs was to determine the control parameters and limitations for the Microtrac analyzer and the computer. All data from the runs was used to develop the software to control feed rate to the mill and classifier operation.

Ten mill runs were completed utilizing the feed rates and rotor speeds as presented in Table 4.1. The classifier fan speed was maintained at 4400 rpm throughout the tests.

Table 4.1

Run No.	Feed Rate (lb/hr)	Rotor Speed (rpm)
1	400	800
2	400	675
3	550	700
4	550	550
5	750	750
6	750	550
7	800	550
8	800	750
9	900	580
10	900	580

These parameters were chosen from Activity 1 test results and encompassed the maximum and minimum feed rates to the mill, as well as the maximum and minimum classifier rotor speeds required to produce a 45 μm product. When operating outside these operating conditions, classifier efficiency dropped rapidly.

4.3 Off-line Testing of Microtrac Particle Size Analyzer

Extensive off-line testing of the Microtrac particle size analyzer in the dry sampling mode highlighted several factors which resulted in inconsistent particle size analysis. The major problems encountered were:

- Particle agglomeration
- A fluctuating feed rate to the sample cell caused by variations in the vibrating feeder performance.
- Particle bridging at the sample feed hopper.
- Blinding of hopper discharge screen.
- Particle bridging at the feed cone.

These factors resulted in fluctuating readings and inconsistent particle size analysis. As time did not permit the satisfactory resolution of these problems, it was decided to operate the Microtrac in the wet sampling mode.

Inconsistent particle size analysis of calcium carbonate samples still predominated, even when operating in the wet testing mode. Petrographic evaluation revealed that the Steep Rock calcium carbonate had a double refractive index, therefore the light striking the particles was scattered in a random manner. Statistical data from the baseline runs was used to develop a "correction factor" to account for the discrepancy (see Figure 4.3-F1). This correction factor was then incorporated into the computer software.

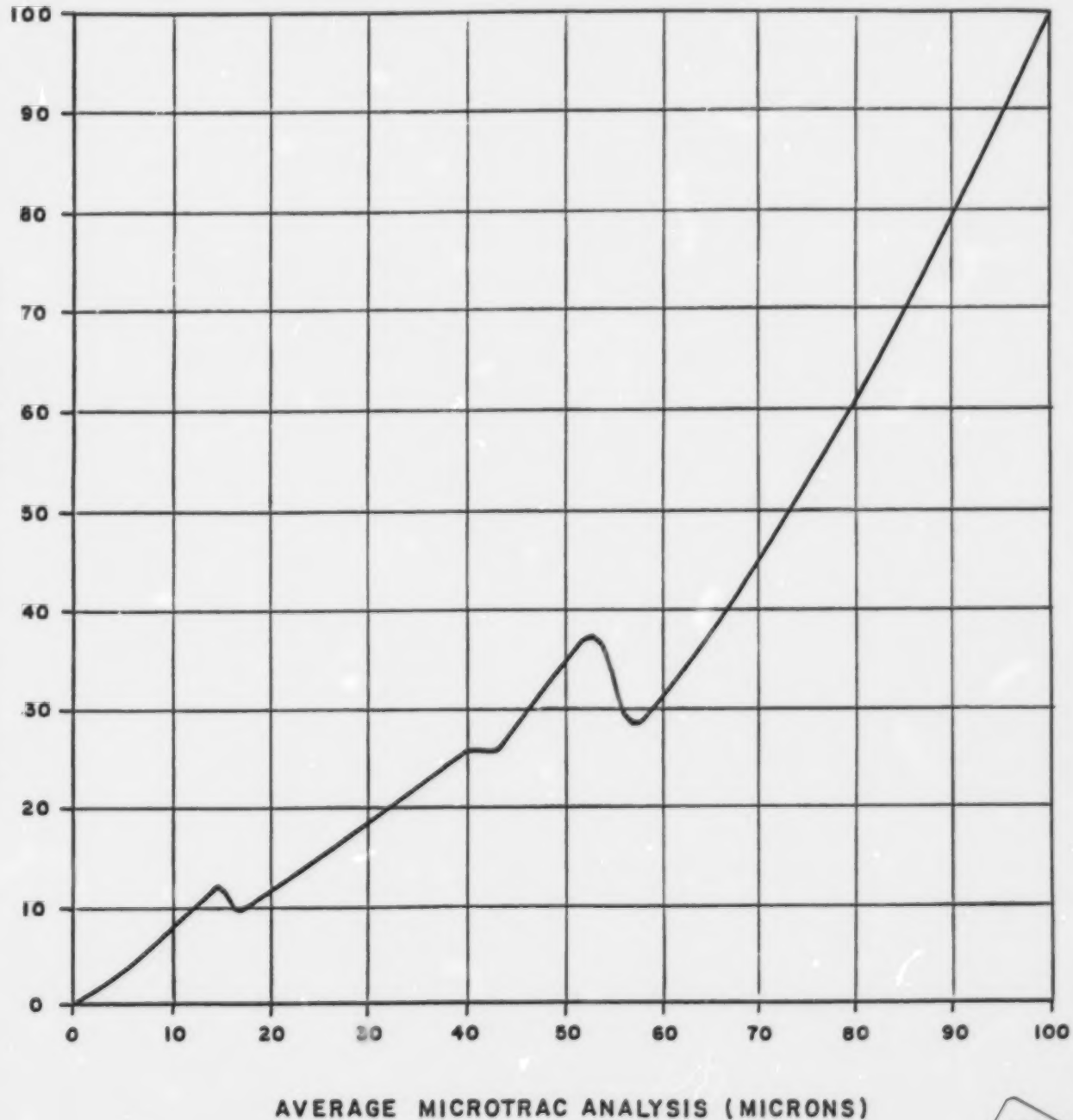
4.4 Computer Control Philosophy

Classifier performance and efficiency were affected by the size of the material feed to the classifier, the feed rate and the ability of the classifier and internal fan to disperse

Figure 4.3-F1

D.S.S. – CANADA CEMENT LAFARGE LTD
ENERGY CONSERVATION IN THE INDUSTRIAL
MINERALS SECTOR – COMMINUTION – ACTIVITY 4

CORRECTION FACTORS FOR MICROTRAC ANALYSIS AND CONTROL



WD1

adequately the particles in the air stream. As the classifier became overloaded, particles were unsatisfactorily dispersed, and classifier efficiency will dropped. The product was affected by controlling the mill feed rate, classifier feed size and feed rate. The rotor speed was adjusted to central the cutsize of the product.

Therefore, by controlling mill feed rate and the rotor speed of the classifier, the circuit can be operated to achieve the desired product size.

The internal fan speed was operated at 4400 rpm for all test mill runs. At this speed, the airflow was sufficient to disperse particles adequately, providing the feed rates to the classifier varied from 0 to 100 kg/hr (for a 45 μm product). These parameters were based on Activity 1 and Activity 4 baseline results. Control of the circuit involved adjusting the mill feed rate, and classifier rotor speed.

Computer software was developed to accept information such as mill feed rate, and particle size analysis of classifier product.

The data received from the Microtrac was processed by the computer, programmed to meet Activity 4 objectives and output specific instructions to "Optomux" logic controllers. This controller signalled individual I/O (input/output) modules that converted these signals to the corresponding signal requirements of the equipment i.e. 4-20 mA signal were required for the Amvest classifier and digital (transistor to transistor logic) control signal for vibrating feeder. Control flow schemes are illustrated in Figures 4.4-F1, showing circuit control based on particle size, and 4.4-F2, showing circuit control based on particle size and production rate.

FIGURE 4.4-F1

DSS-CANADA CEMENT LAFARGE
ACTIVITY 4
COMPUTER CONTROLLED MILL/CLASSIFIER CIRCUIT
CIRCUIT CONTROL BASED ON PARTICLE SPEC ONLY

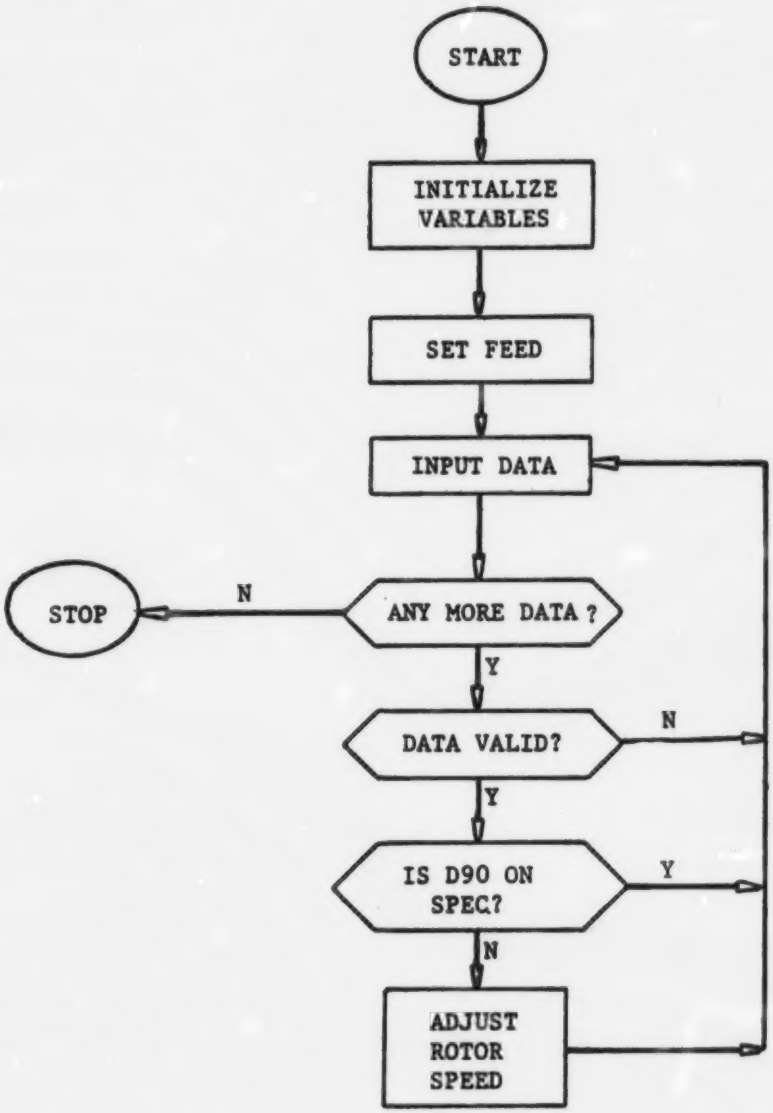


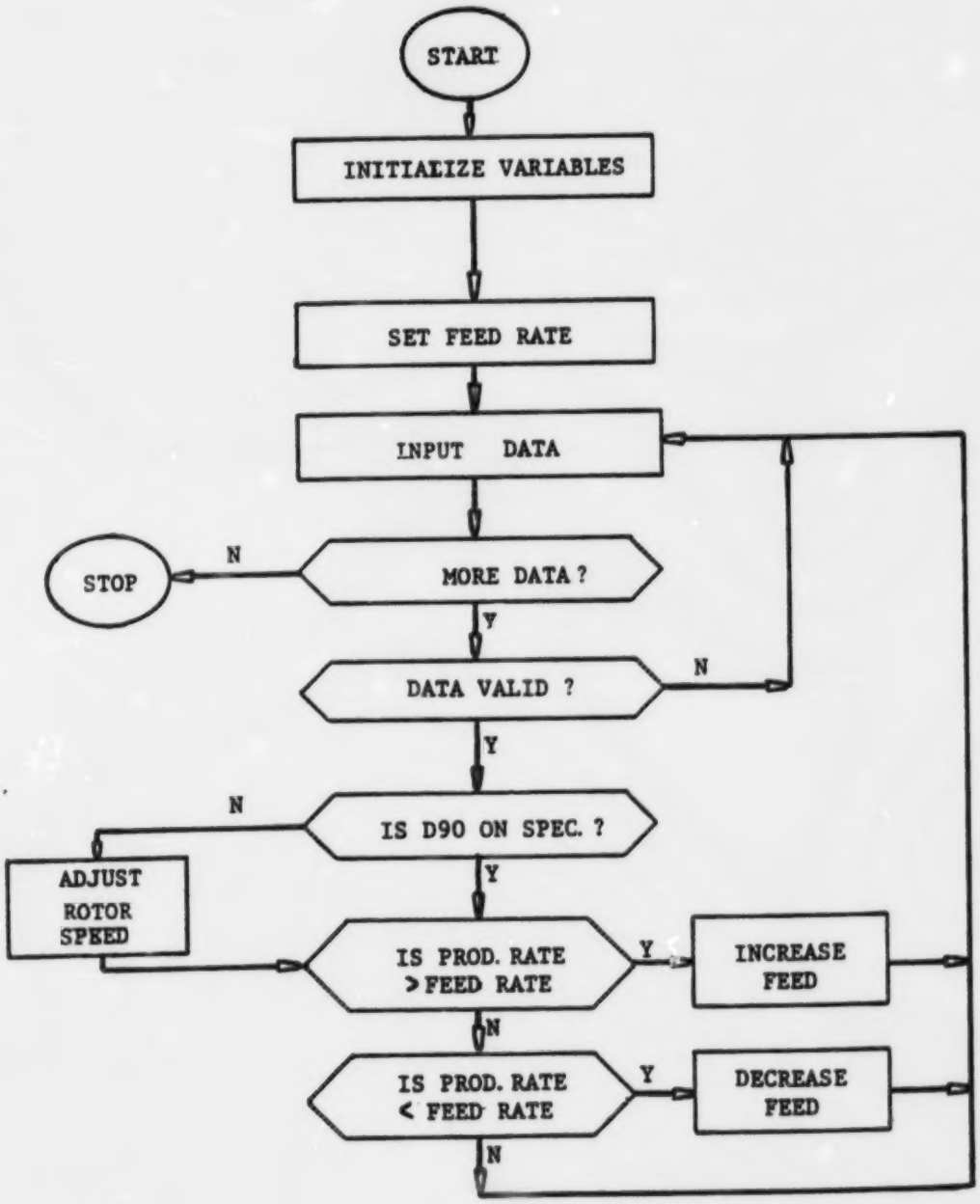
Figure 4.4-F2

DSS-CANADA CEMENT LAFARGE
ACTIVITY 4

COMPUTER CONTROLLED MILL/CLASSIFIER CIRCUIT

CIRCUIT CONTROL BASED ON PARTICLE SIZE

AND PRODUCTION/FEED RATE



4.5 Computer Controlled Mill Runs

Twelve tests were completed averaging 3 to 5 hours in duration. Feed rates were varied from 250 kg/hr to 454 kg/hr. Typical operating parameters are shown in Table 4.5-T1.

Samples of classifier product were manually taken and analyzed, using the Microtrac every 6 minutes. Based on the size distribution data from the Microtrac, the MS-5 rotor speed was either adjusted manually based on information from the computer or adjusted directly by the computer itself.

Control objectives investigated during the twelve runs were to:

- Maximize throughput while maintaining target product size.
- Minimize product size fluctuations.
- Determine recovery time for circuit to re-establish itself after an upset.
- Reduce energy requirements for milling, classification and air handling.

Table 4.5-T1

COMPUTER CONTROLLED CLASSIFIER TESTS

TYPICAL OPERATING PARAMETERS

Pressure Difference (mm W.G.)

o	Fan	427 mm
o	Aspirator	117 mm
o	Cyclone	36 mm

Static Pressure (mm W.G.)

o	Fan Intake	-173 mm
o	Fan Outlet	+257 mm
o	Uptake	-142 mm
o	Cyclone Inlet	-122 mm
o	Cyclone Outlet	-170 mm
o	Dust Collector	-170 mm

Current Measurements (amps)

o	Fan	7.8
o	Mill	18/19
o	Classifier	8/9

4.6 Sampling

Grab samples of classifier product were taken every 6 minutes for Microtrac analysis. A composite of these samples was made for each feed rate product size combination for Sedigraph analysis and control of the circuit.

4.7 Screen and Particle Size Analysis

Screen analysis on all fractions were completed by conventional metallurgical procedures. Minus 200 mesh material was further analyzed with a Sedigraph.

4.8 Clean Up and Disposal

The calcium carbonate product was collected in 205 litre drums, and transferred by a Bobcat front end loader to a 10.7 cubic meter bin. A plastic liner in the bin was used to prevent dusting of the calcium carbonate during transport and disposal at the landfill site. Attempts to recycle the material proved unsuccessful due to material handling problems.

5.0 PILOT PLANT TEST RESULTS

5.1 Run No. 1

Duration: 3 hours 30 minutes

Feed Rate: 340 kg/hr.

This run was used to mechanically shakedown the grinding/classification and computer circuit. Samples were taken every 12 minutes, and the circuit was controlled manually based on data generated by the computer.

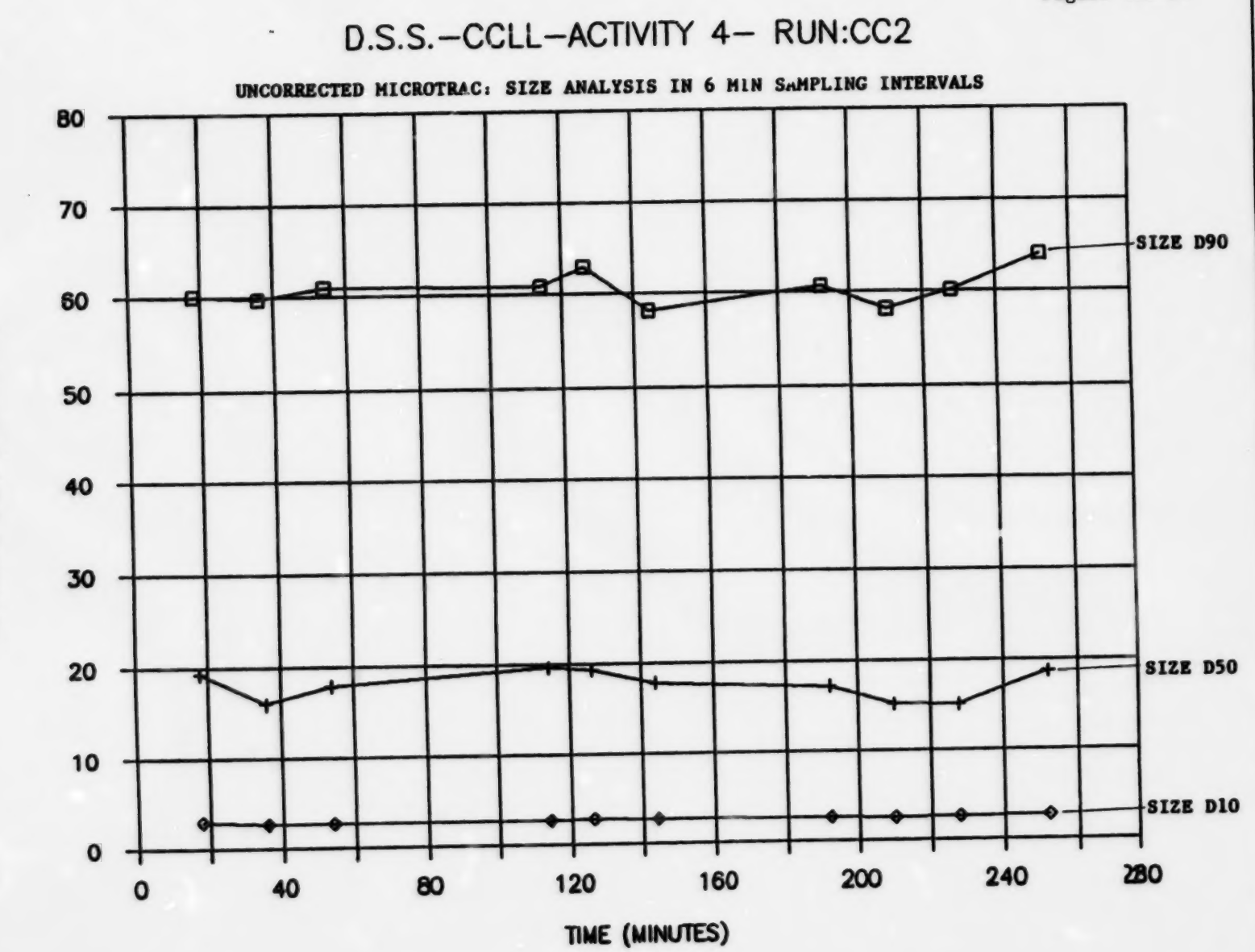
5.2 Run No. 2

Duration	5 hours
Feed Rate:	250 kg/hr. for 1 hour 30 minutes 272 kg/hr. for 4 hours
D_{90} Target Size:	D_{90} @ 60 microns.
Control of Circuit:	Manual
Sampling:	Every 12 minutes

The grinding classification circuit was operated manually using particle size data generated from the computer. A target size of 90% passing 60 microns (Microtrac) was maintained, using computer generated data.

Figure 5.2 F-1 shows a plot of particle size versus time for Run No. 2.

Figure 5.2-F1


D.S.S.–CCLL–ACTIVITY 4– RUN:CC2
UNCORRECTED MICROTRAC: SIZE ANALYSIS IN 6 MIN SAMPLING INTERVALS
PRODUCT
PARTICLE SIZE (MICRONS)
80
70
60
50
40
30
20
10
0
0
40
80
120
160
200
240
280
TIME (MINUTES)
SIZE D90
SIZE D50
SIZE D10

5.3 Run No. 3

Duration:	4 hrs 18 minutes
Feed Rate:	340 kg/hr for 3 hours 272 kg/hr for 1 hour 18 minutes
D_{90} Target Size:	100% passing 70 microns 100% passing 60 microns
Control of Circuit:	Manual
Sampling:	Every 12 minutes after circuit stabilized.

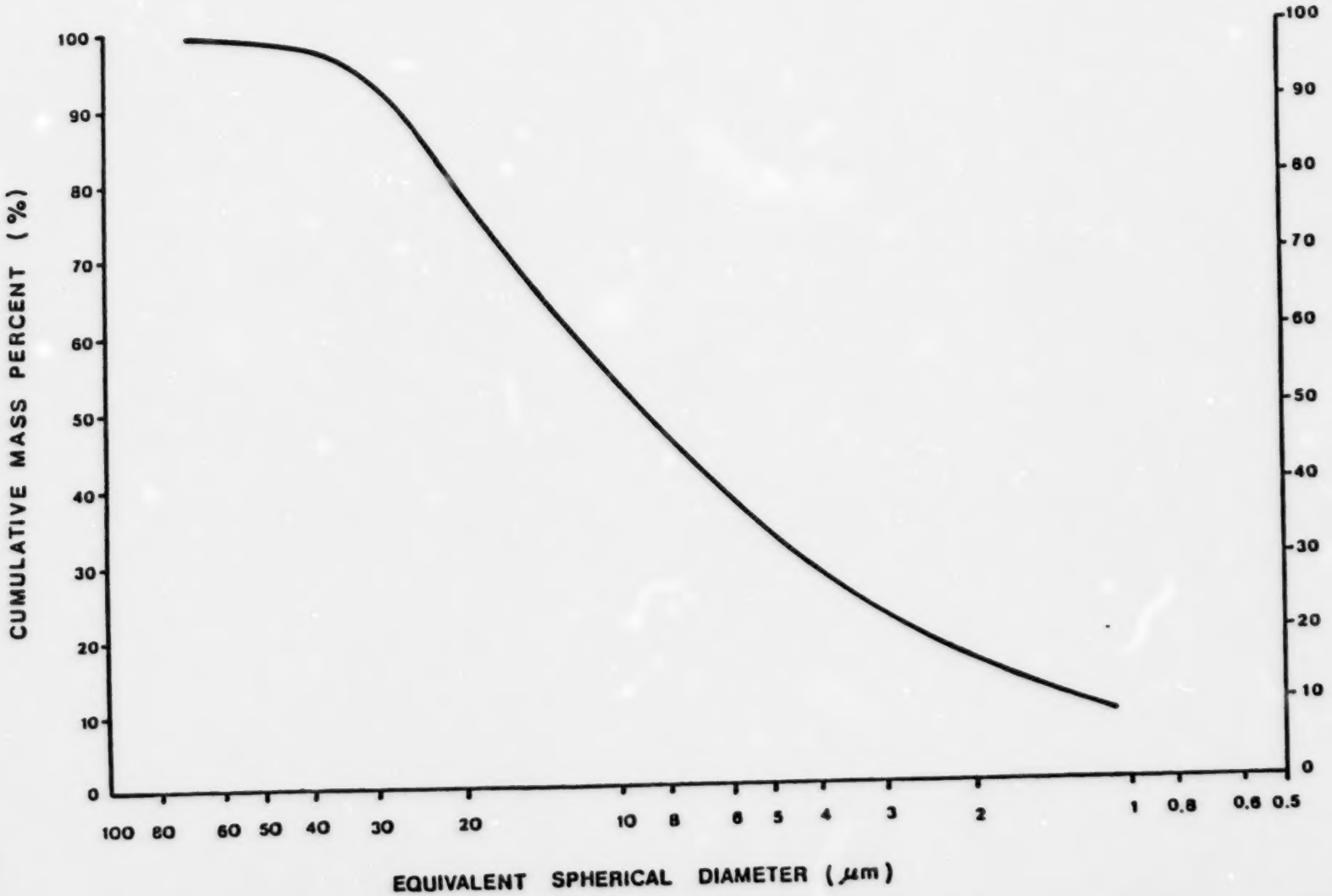
Run No. 3 was a continuation of Run No. 2, with the circuit still being adjusted manually based on instructions from the computer. No major technical problems were encountered and confidence with the software and circuit set-up enabled Witteck to decide to go with full automation in the following test. Particle size distribution curve is shown in Figure 5.3-F1.

PRODUCT

PARTICLE SIZE DISTRIBUTION

RUN NO. CC 3

Figure 5.3-F1



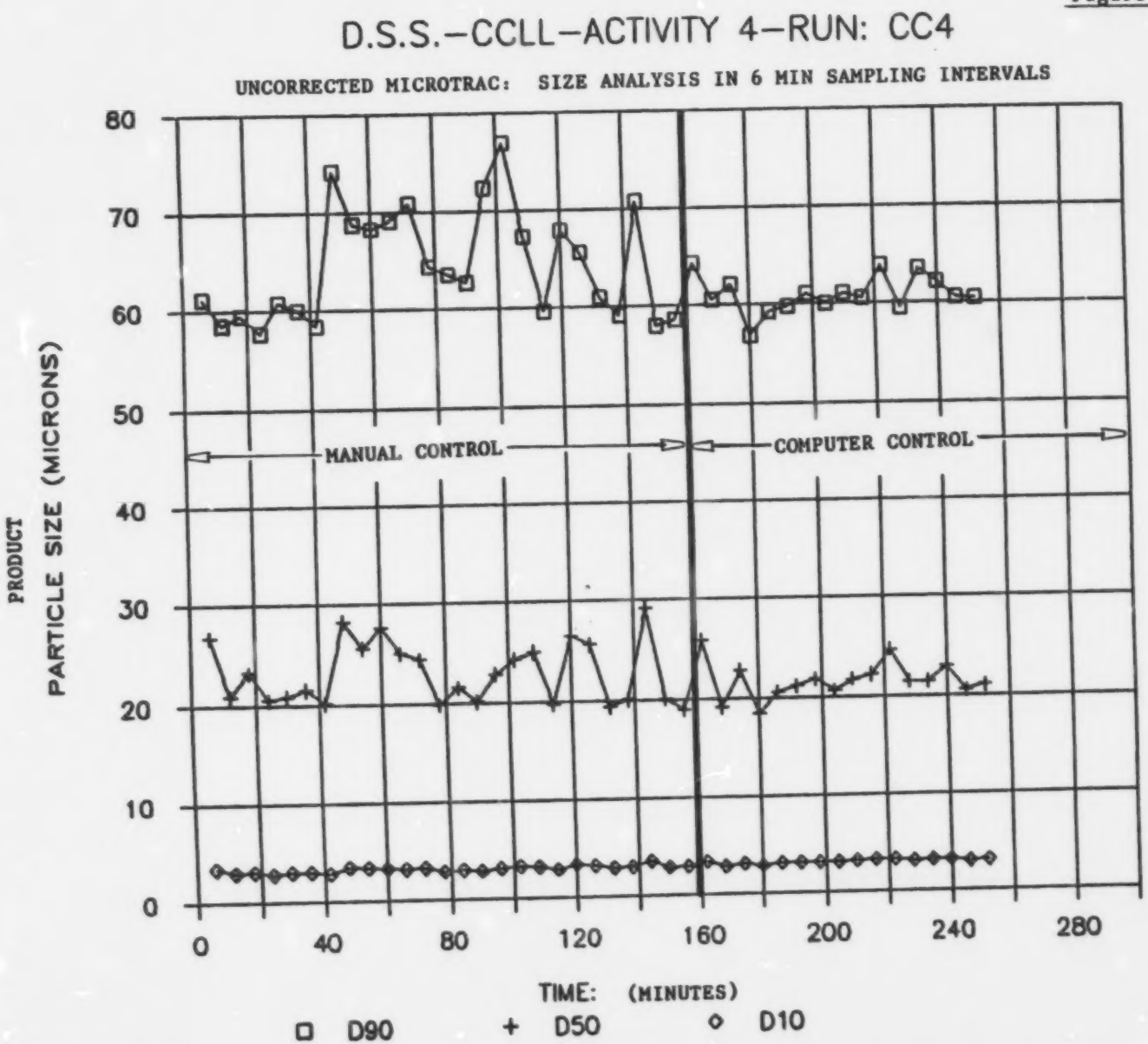
5.4 Run No. 4

Duration:	4 hrs 30 minutes
Feed Rate:	340 kg/hr for 48 minutes 363 kg/hr for 30 minutes 386 kg/hr for 30 minutes 408 kg/hr for 30 minutes 454 kg/hr for 2 hr. 12 minutes
D_{90} Target Size:	100% passing 70 microns 100% passing 60 microns
Control of Circuit:	Manual for 2 hr. 40 minutes. Computer controlled for remainder of test.
Sampling:	Every 6 minutes

Feed rate was increased gradually from 340 kg/hr to 454 kg/hr with manual control of the circuit to maintain product specifications. Sampling rate was increased to every 6 minutes compared to every 12 minutes in the previous tests for tighter control of product specifications.

After 3 hours of operation of the circuit was placed under computer control. As shown in Figure 5.4-F1, the variation in product size at D90 and D50 levels decreased significantly. Particle size distribution curve is shown in Figure 5.4-F2. Material Flow is shown in Figure 5.4-F3.

Figure 5.4-F1


D.S.S.–CCLL–ACTIVITY 4–RUN: CC4
UNCORRECTED MICROTRAC: SIZE ANALYSIS IN 6 MIN SAMPLING INTERVALS
PRODUCT
PARTICLE SIZE (MICRONS)
80
70
60
50
40
30
20
10
0
MANUAL CONTROL
COMPUTER CONTROL
0
40
80
120
160
200
240
280
TIME: (MINUTES)
□ D90
+ D50
◇ D10

PRODUCT

PARTICLE SIZE DISTRIBUTION

RUN No.CC 4

Figure 5.4-F2

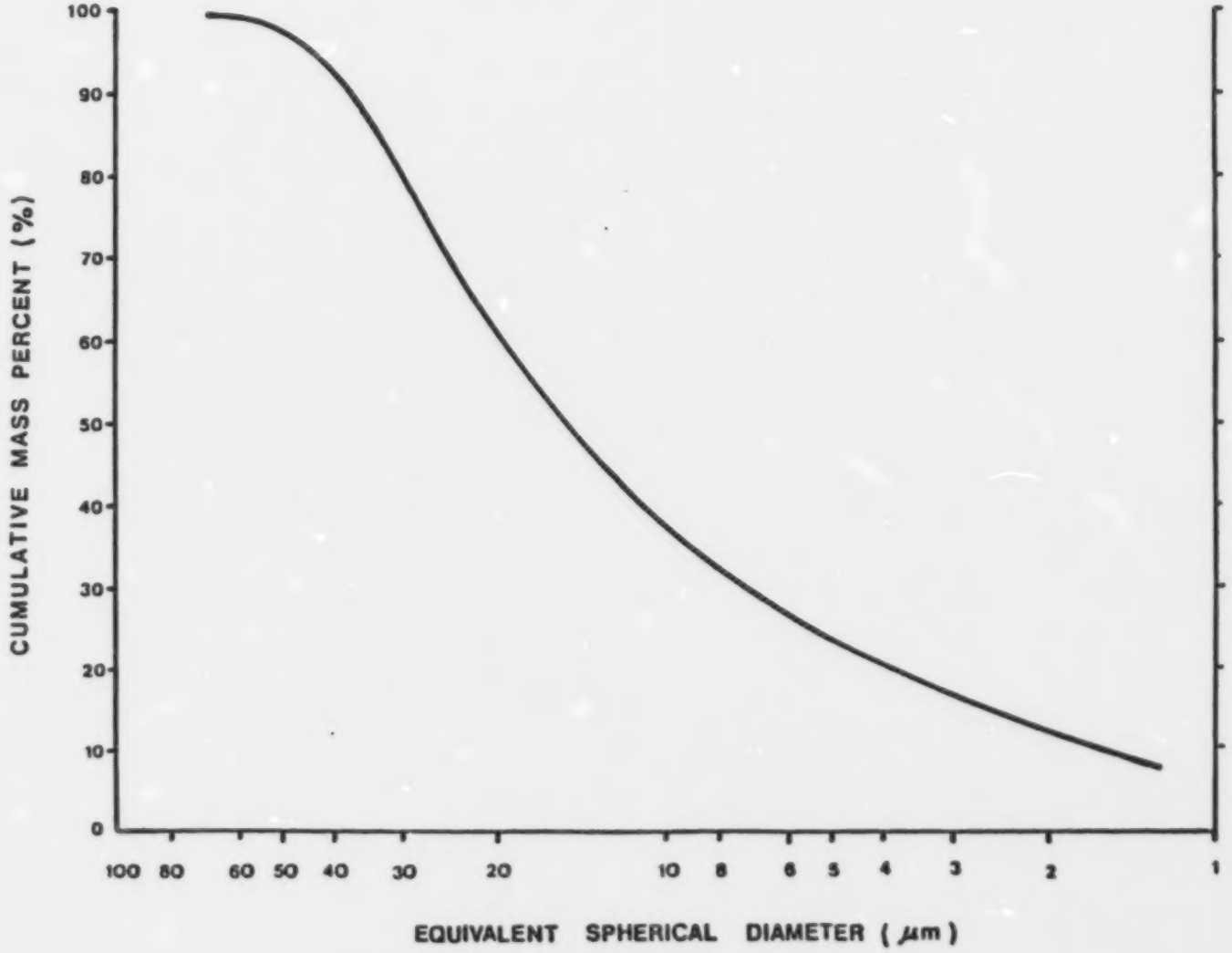
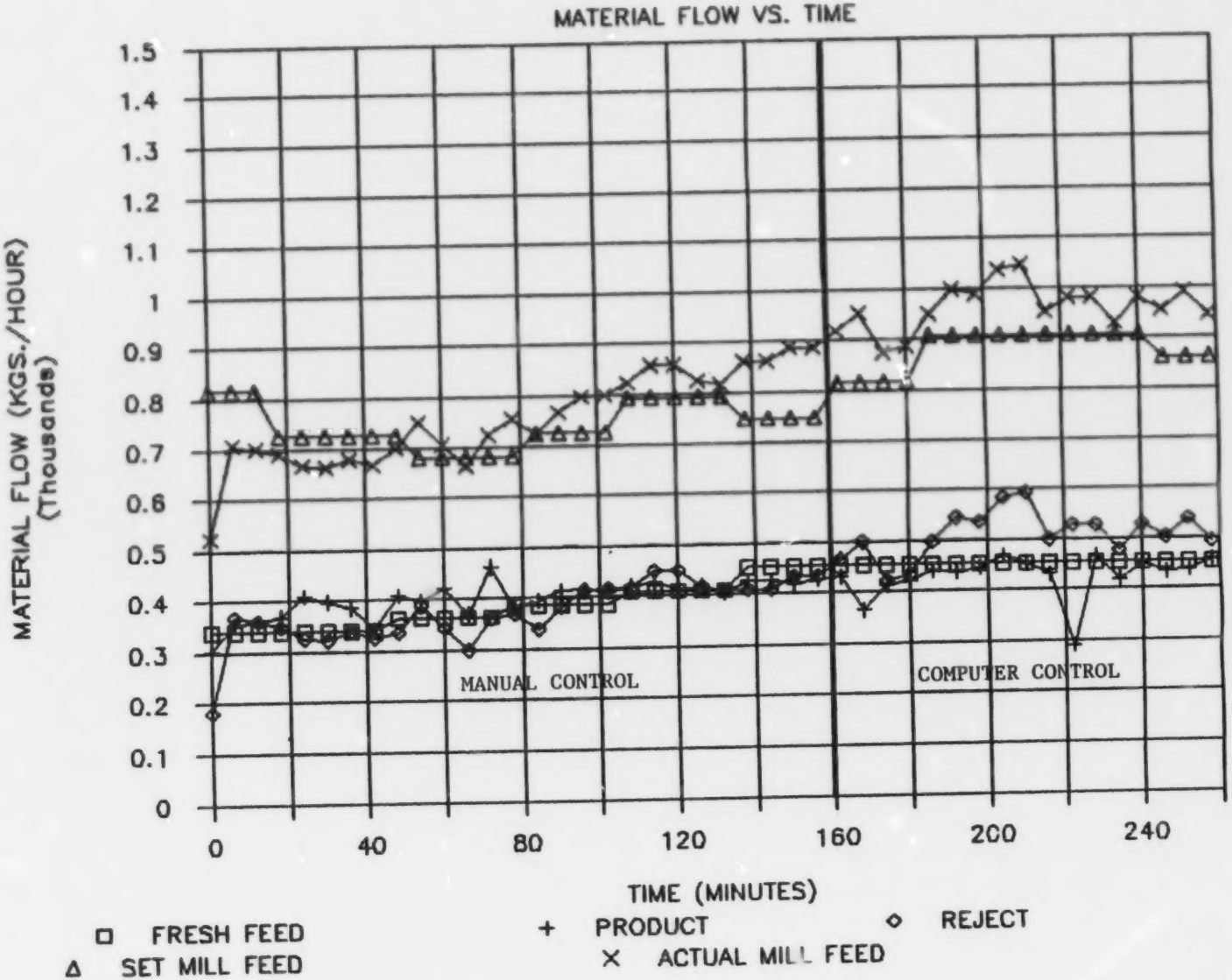


Figure 5.4-F3

D.S.S.–CCLL–ACTIVITY 4–CC4



5.5 Run No. 5

Duration:	5 hours
Feed Rate:	386 kg/hr
D_{90} Target Size:	D_{90} @ 60 microns D_{90} @ 50 microns D_{90} @ 40 microns
Control of Circuit:	Computer
Sampling:	Every 6 minutes

The objective of this test was to determine the time required for the circuit to adjust to new product specifications. As shown in Figure 5.5-F1 approximately 40 minutes is required for this particular circuit to adjust from a target specification of 60 microns to 50 microns and then to 40 microns. The particle size distribution curve is shown in Figure 5.5-F2. Material Flow vs Time is shown in Figure 5.5-F3.

Figure 5.5-F1

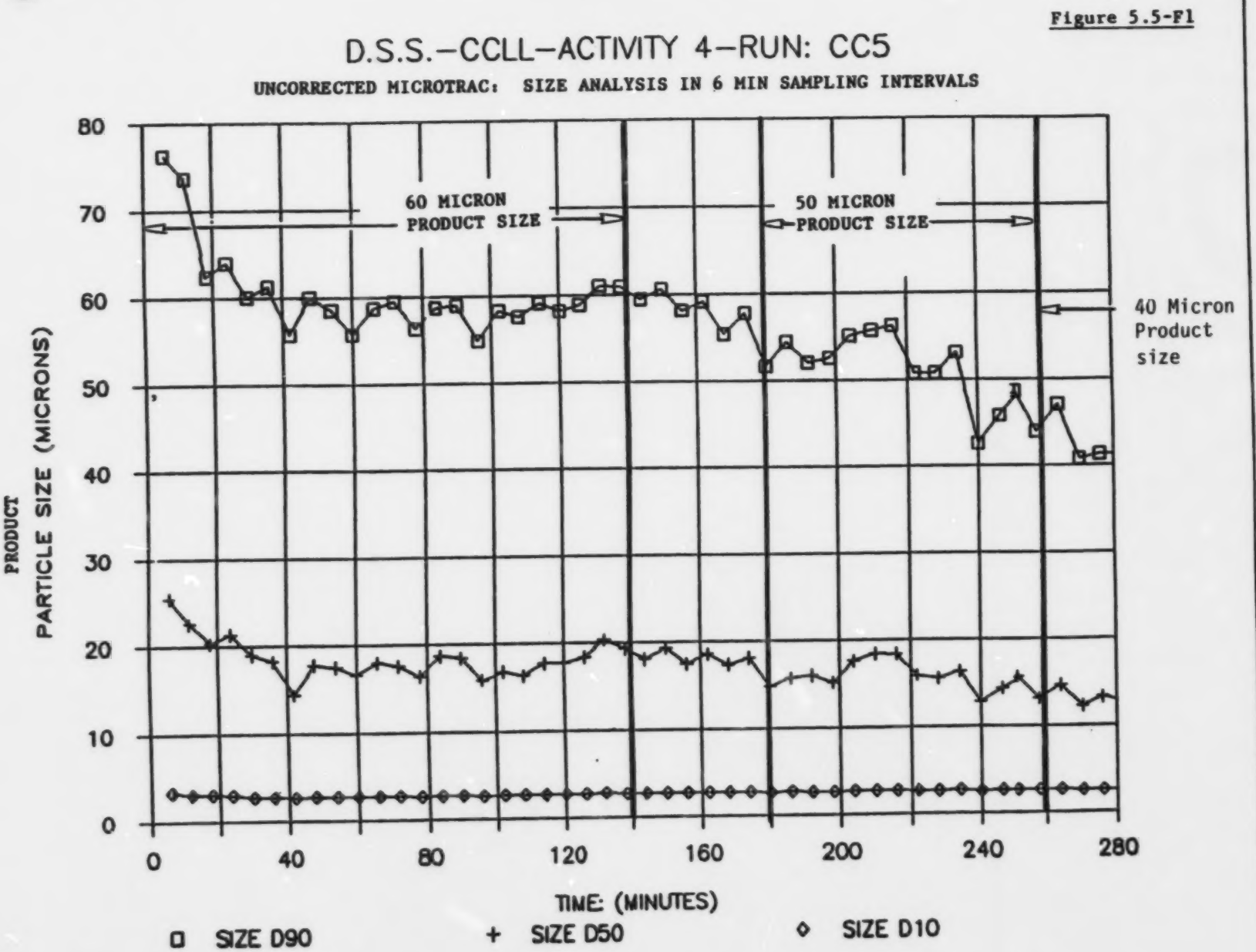

D.S.S.–CCLL–ACTIVITY 4–RUN: CC5
UNCORRECTED MICROTRAC: SIZE ANALYSIS IN 6 MIN SAMPLING INTERVALS
60 MICRON PRODUCT SIZE
50 MICRON PRODUCT SIZE
40 Micron Product size
PRODUCT PARTICLE SIZE (MICRONS)
80
70
60
50
40
30
20
10
0
0
40
80
120
160
200
240
280
TIME: (MINUTES)
SIZE D90
SIZE D50
SIZE D10

Figure 5.5-F2

PRODUCT

PARTICLE SIZE DISTRIBUTION

RUN NO. CC 5

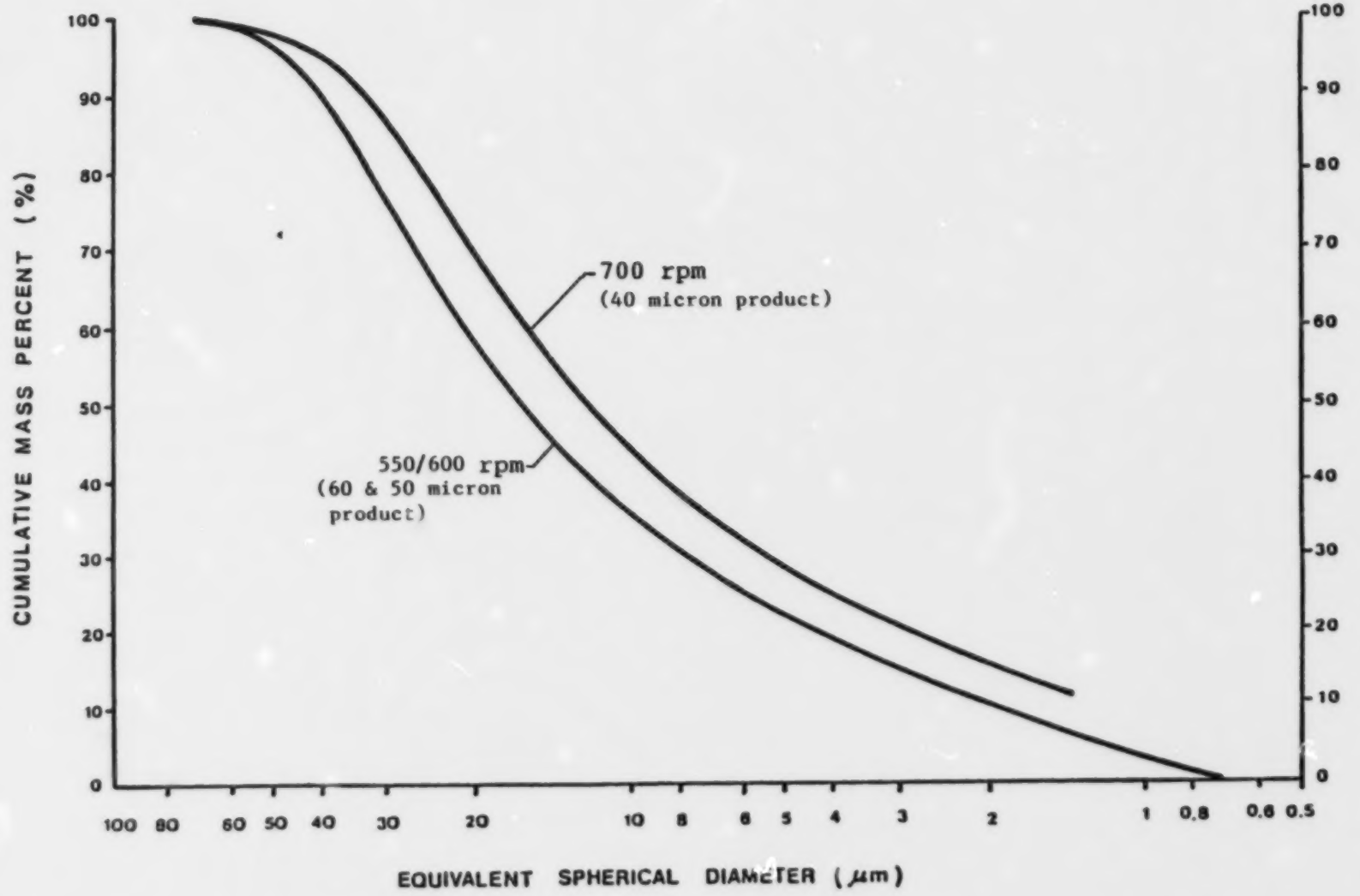
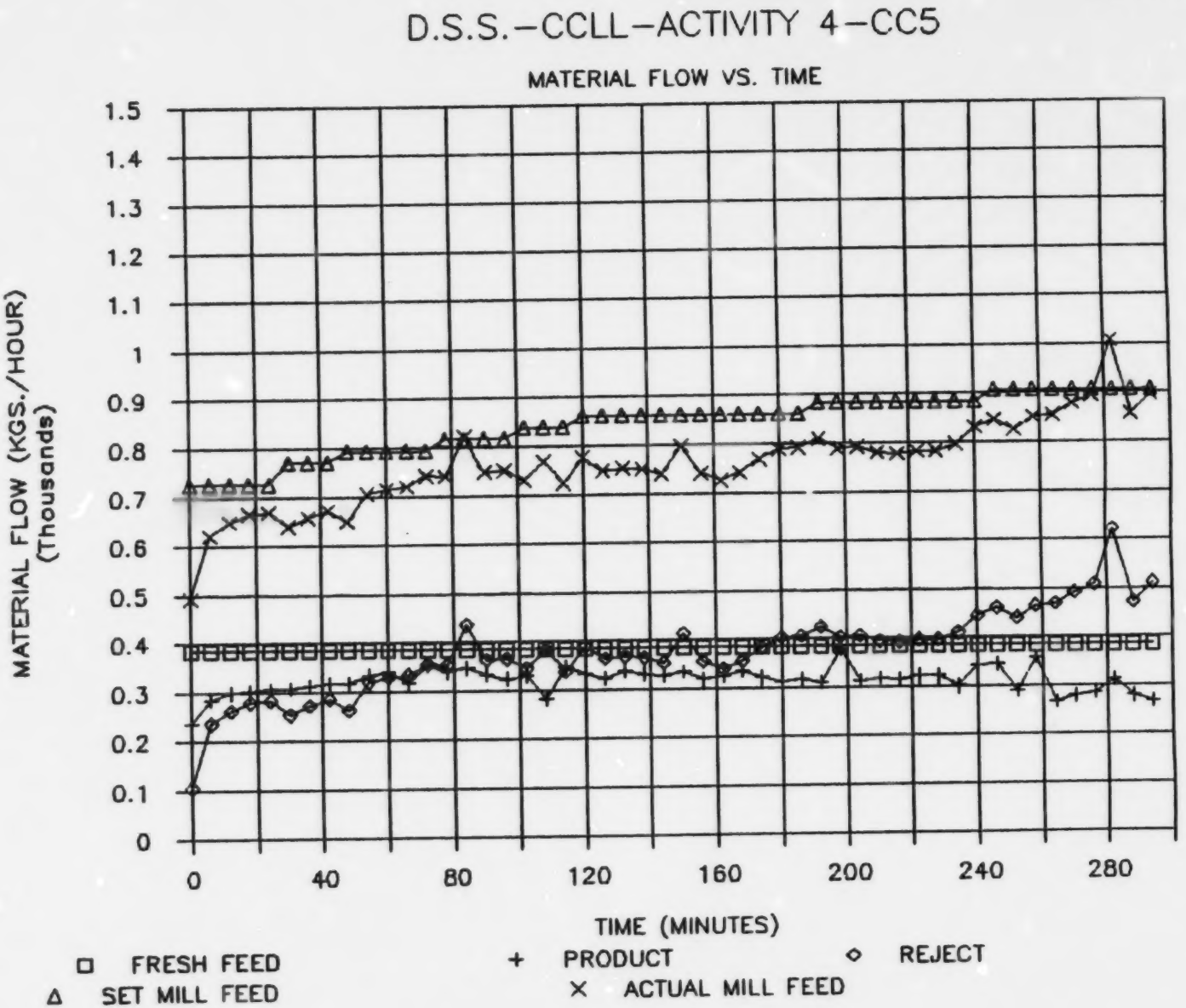


Figure 5.5-F3


D.S.S.–CCLL–ACTIVITY 4–CC5
MATERIAL FLOW VS. TIME
MATERIAL FLOW (KGS./HOUR)
(Thousands)
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
40
80
120
160
200
240
280
TIME (MINUTES)
FRESH FEED
SET MILL FEED
PRODUCT
ACTUAL MILL FEED
REJECT

5.6 Run No. 6

Duration:	4 hrs 36 minutes
Feed Rate:	386 kg/hr
D_{90} Target Size:	D_{90} @ 40 microns D_{90} @ 30 microns D_{90} @ 40 microns
Control of Circuit:	Computer
Sampling:	Every 6 minutes

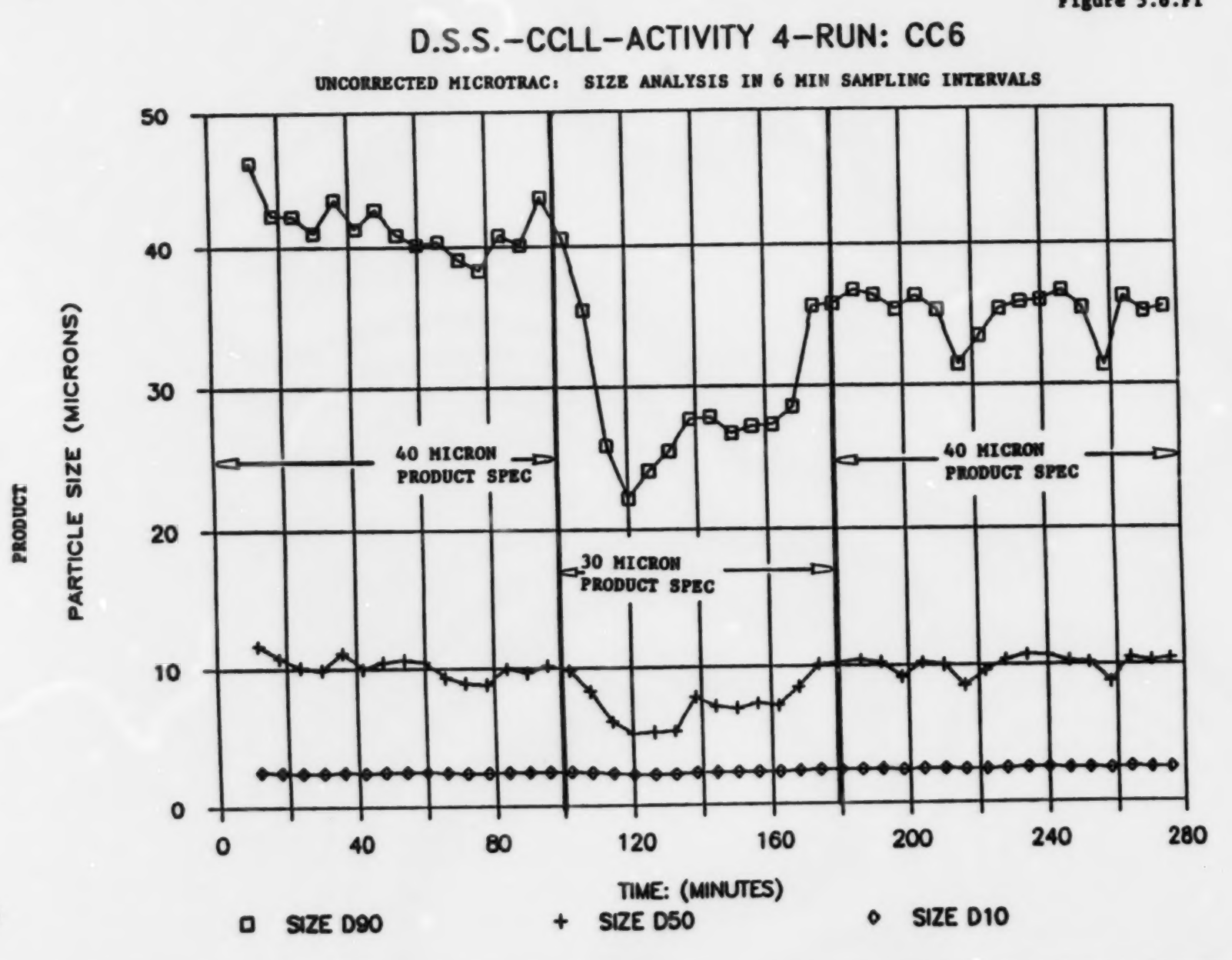
The circuit was purposely unbalanced again in this test, with the classifier rotor speed adjusted from 750 to 850 rpm. Figure 5.6-F1 illustrates that about 40 minutes was required for the circuit to adjust to a new, smaller D90 target size. Increasing the D90 target size brings about an instantaneous change, with very little "searching" by the circuit for the target size. The particle size distribution curve is shown in Figure 5.6-F2.

The circuit was operating at maximum capacity as indicated by the feed set point being in excess of production rate. Excessive feed was collected at the mill feed chute and returned to the feed hopper.

The circulating load continued to increase throughout the test, which indicated the circuit had not stabilized. The circulating load continued to increase despite the size set point was increased from 30 microns to 40 microns.

A plot of material flow versus time is shown in Figure 5.6-F3.

Figure 5.6.F1



PRODUCT

PRODUCT

PARTICLE SIZE DISTRIBUTION

RUN NO. CC 6

Figure 5.6-F2

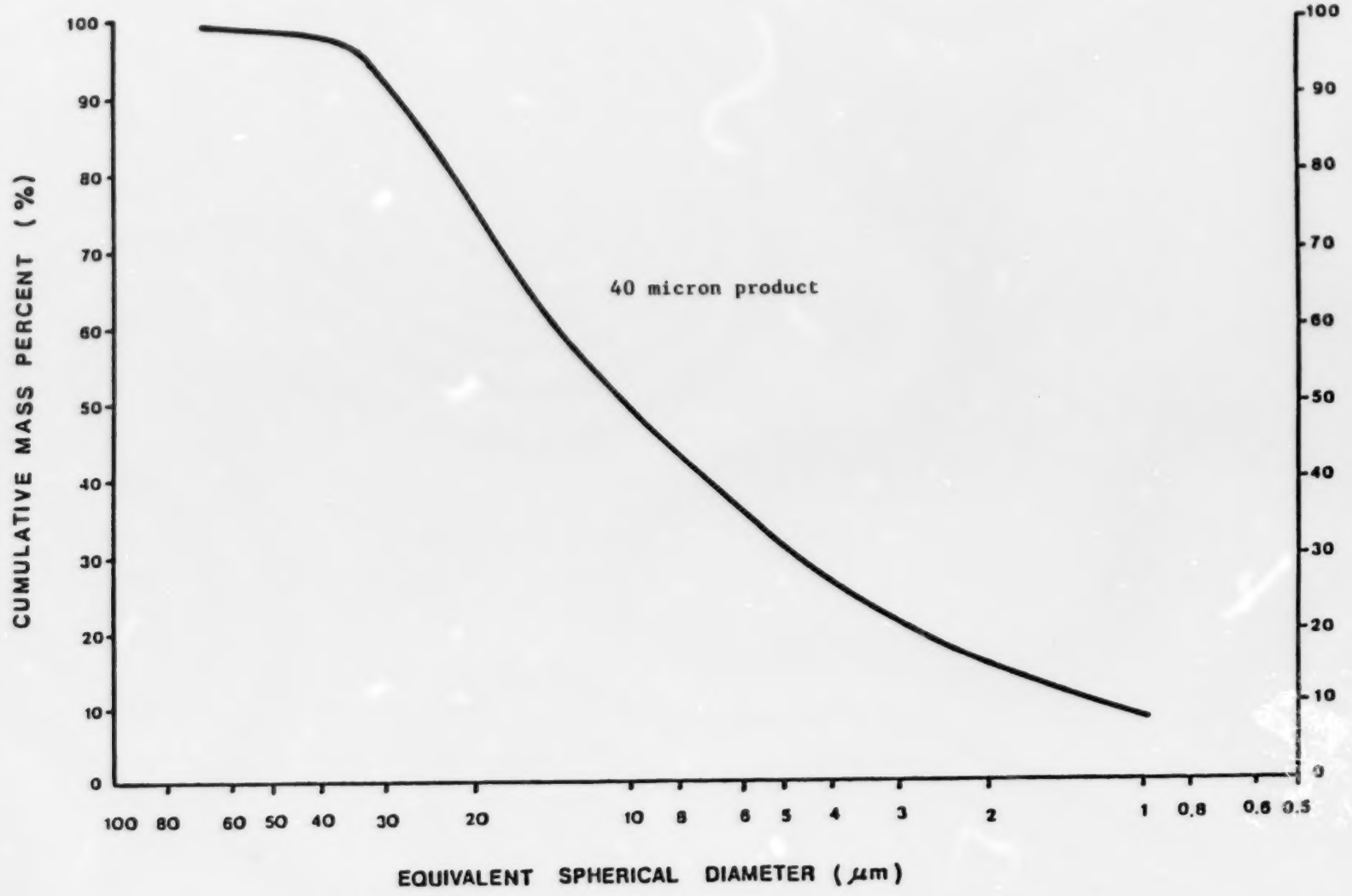
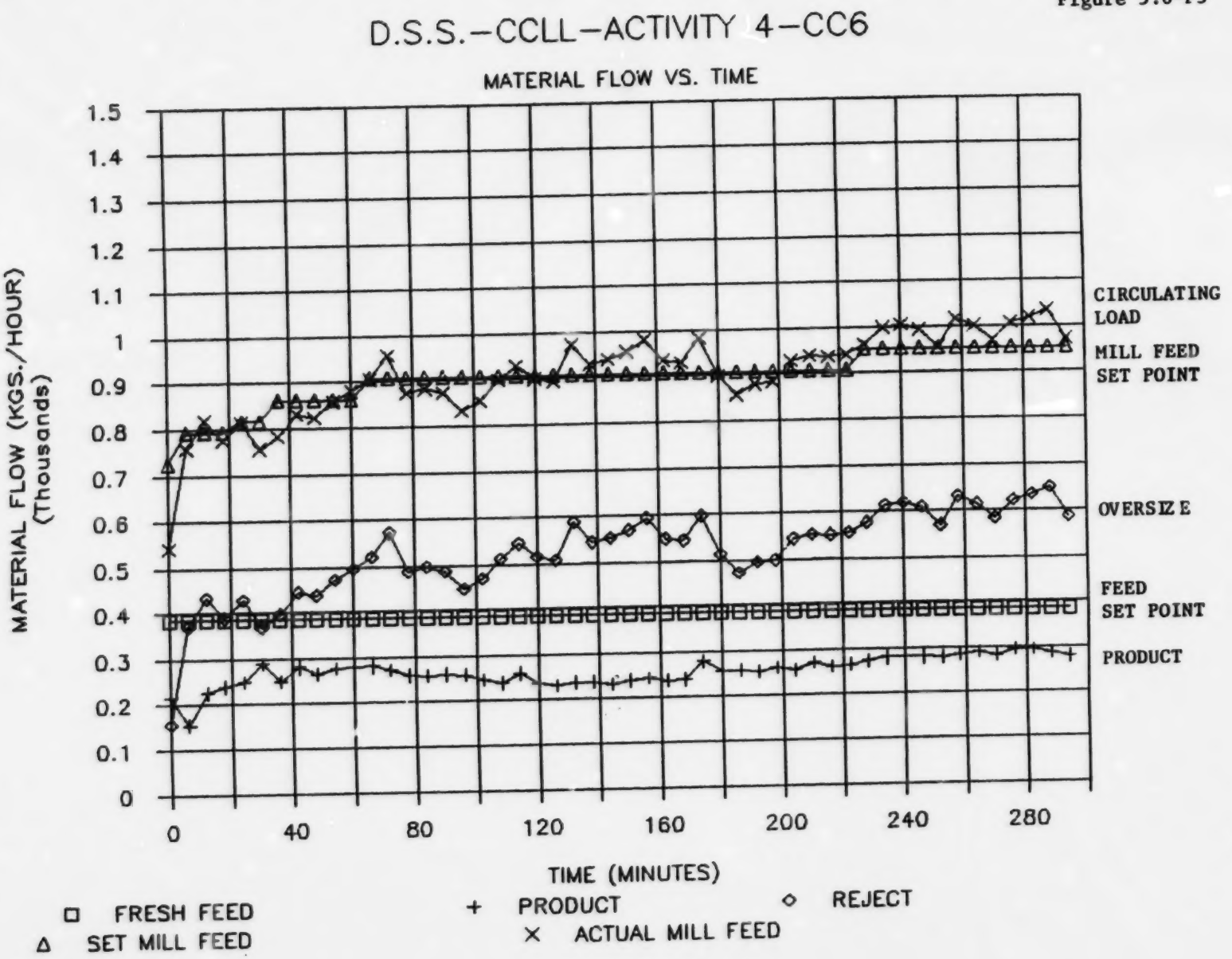


Figure 5.6-F3


D.S.S.–CCLL–ACTIVITY 4–CC6
MATERIAL FLOW VS. TIME
MATERIAL FLOW (KGS./HOUR)
(Thousands)
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
40
80
120
160
200
240
280
TIME (MINUTES)
CIRCULATING LOAD
MILL FEED SET POINT
OVERSIZE
FEED SET POINT
PRODUCT
□ FRESH FEED
Δ SET MILL FEED
+ PRODUCT
◇ REJECT
× ACTUAL MILL FEED

5.7 Run No. 7

Duration:	5 hours
Feed Rate:	386 kg/hr
D_{90} Target Size:	100% passing 40 microns
Control of Circuit:	Manual, then computer controlled
Sampling:	Every 6 minutes

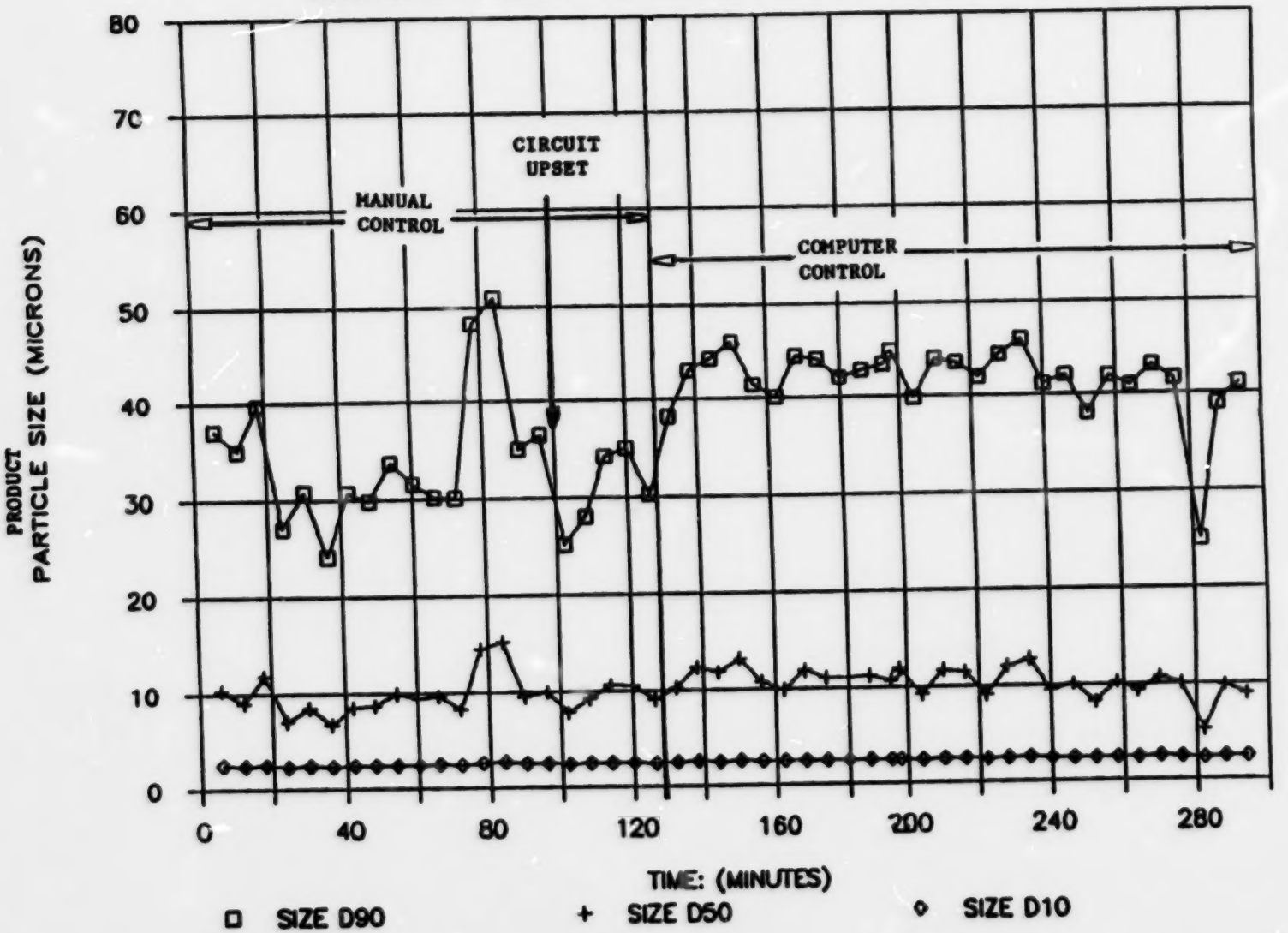
This test demonstrated the difference between manual and computer control of the grinding circuit. As illustrated in Figures 5.7-F1 and 5.7-F3, the circuit was operated manually at first, resulting in a wide variation of product size and feed rate. The particle size distribution curve is shown in Figure 5.7-F2.

It was difficult to bring the circuit into balance using manual control because of the wide swings in feed and recycle to the mill caused the system to plug, resulting in a short shut-down after about 1 1/2 hours of operation. The circuit was restarted, this time under full computer control and was quickly brought into balance for the remainder of the test. Improved control of the product size was achieved within ten minutes of restarting the cirucit. The circulating load was steady for the remainder of the run.

Figure 5.7.F1

D.S.S.–CCLL–ACTIVITY 4–RUN: CC7

UNCORRECTED MICROTRAC: SIZE ANALYSIS IN 6 MIN SAMPLING INTERVALS



PRODUCT

PARTICLE SIZE DISTRIBUTION

RUN NO. CC 7

Figure 5.7-F2

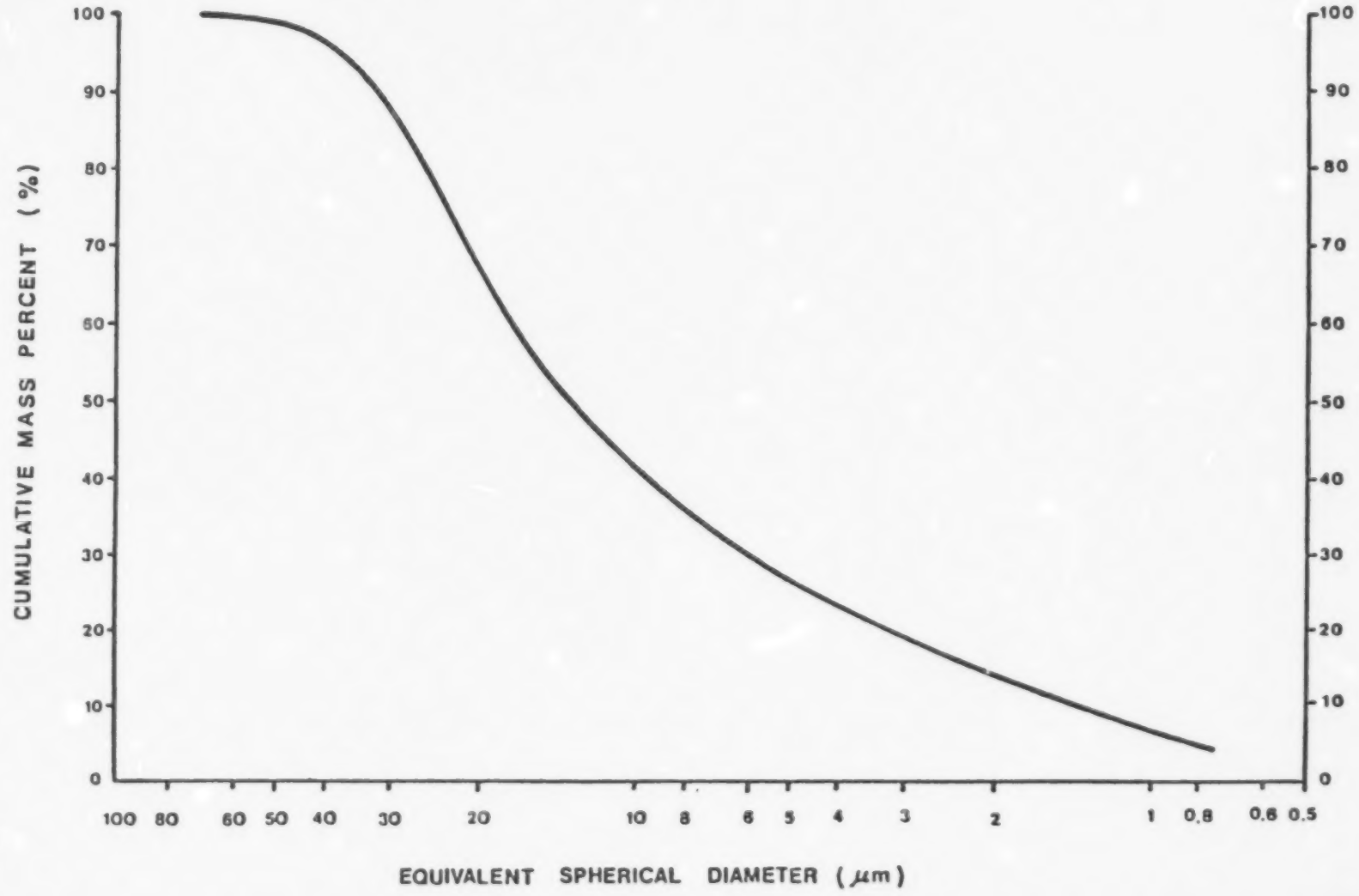
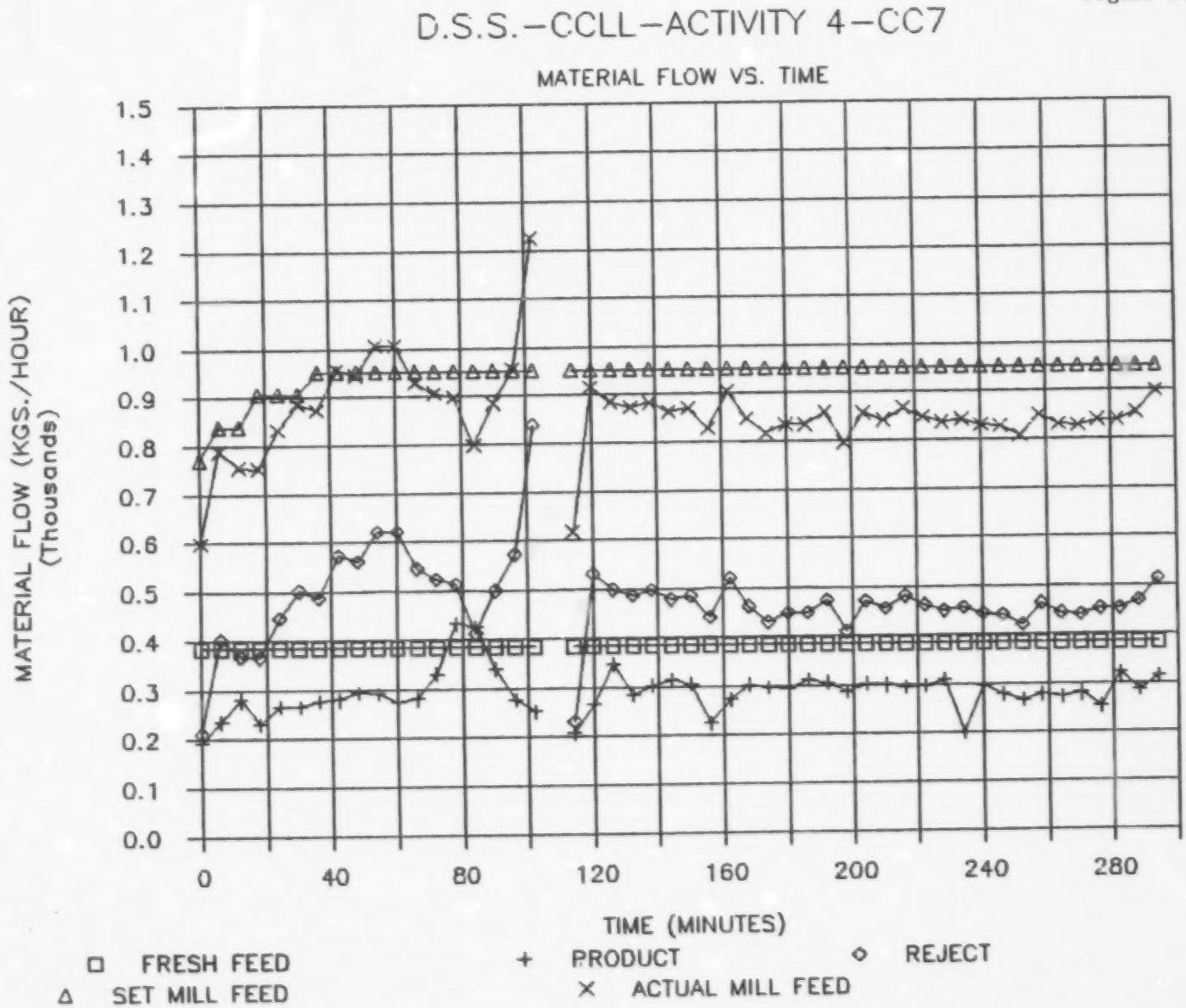


Figure 5.7-F3


D.S.S.–CCLL–ACTIVITY 4–CC7
MATERIAL FLOW VS. TIME
MATERIAL FLOW (KGS./HOUR)
(Thousands)
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
40
80
120
160
200
240
280
TIME (MINUTES)
FRESH FEED
SET MILL FEED
PRODUCT
ACTUAL MILL FEED
REJECT

5.8 Run No. 8

Duration: 4 hrs 20 minutes

Feed Rate: Variable

D_{90} Target Size: 100% 40 microns

Control of Circuit: Computer

Sampling: Every 6 minutes

The objective of this test was to allow the computer to control the feed rate to the mill based on product and recycle weight data given to the computer every six minutes. Due to the time delay between circuit input and output (approximately 15 minutes), the computer control cycled around the set point feed rate. This resulted in large swings in product size, as shown in Figure 5.8-F1. Figure 5.8-F3 shows material flow versus time and clearly indicates the feed cycle. The particle size distribution curve is shown in Figure 5.8-F2.

This mode of control caused an unstable operating condition.

Figure 5.8-F1

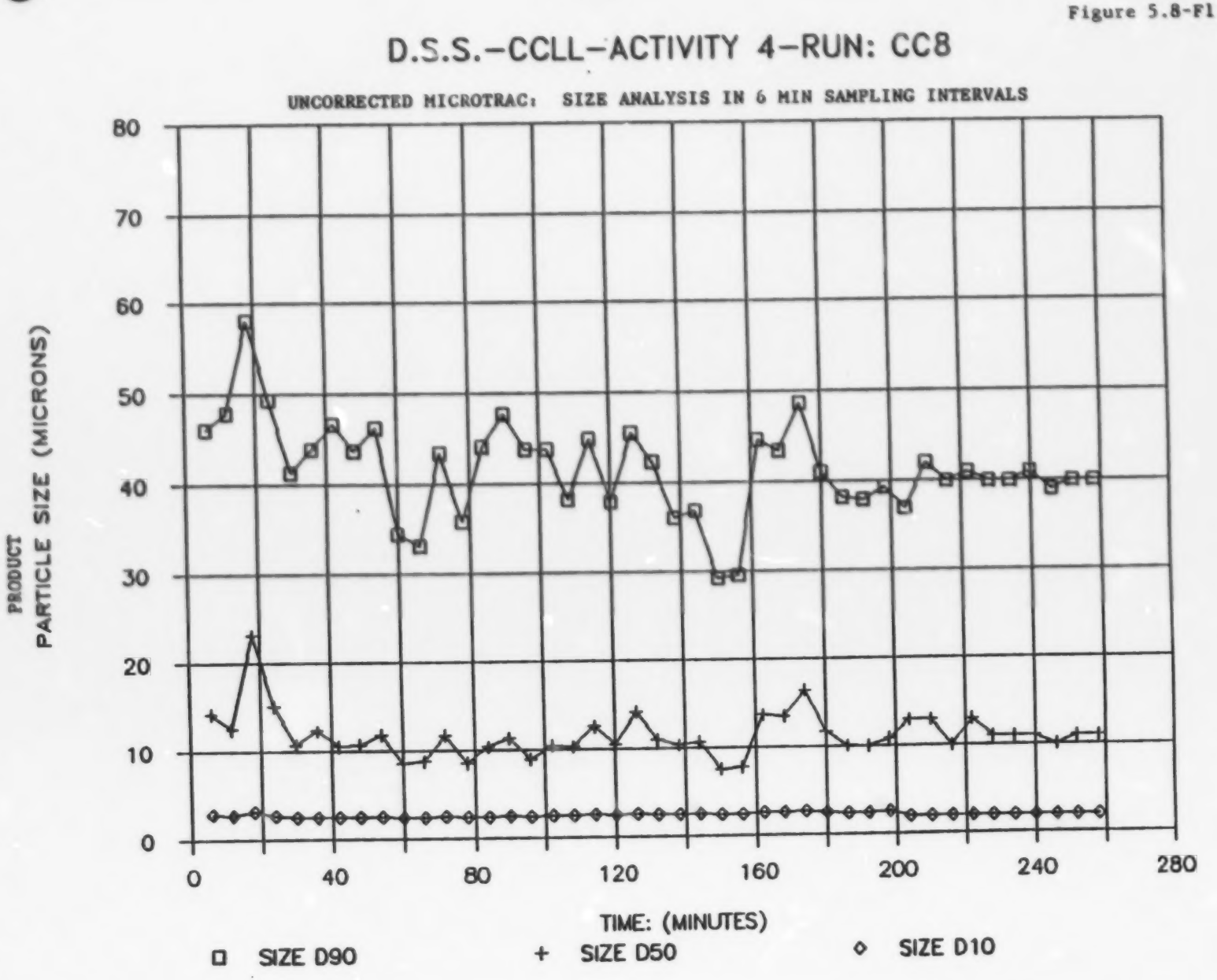

D.S.S.-CCLL-ACTIVITY 4-RUN: CC8
UNCORRECTED MICROTRAC: SIZE ANALYSIS IN 6 MIN SAMPLING INTERVALS
PRODUCT PARTICLE SIZE (MICRONS)
80
70
60
50
40
30
20
10
0
0
40
80
120
160
200
240
280
TIME: (MINUTES)
SIZE D90
SIZE D50
SIZE D10

Figure 5.8-F2

PRODUCT
PARTICLE SIZE DISTRIBUTION
RUN NO. CC 8

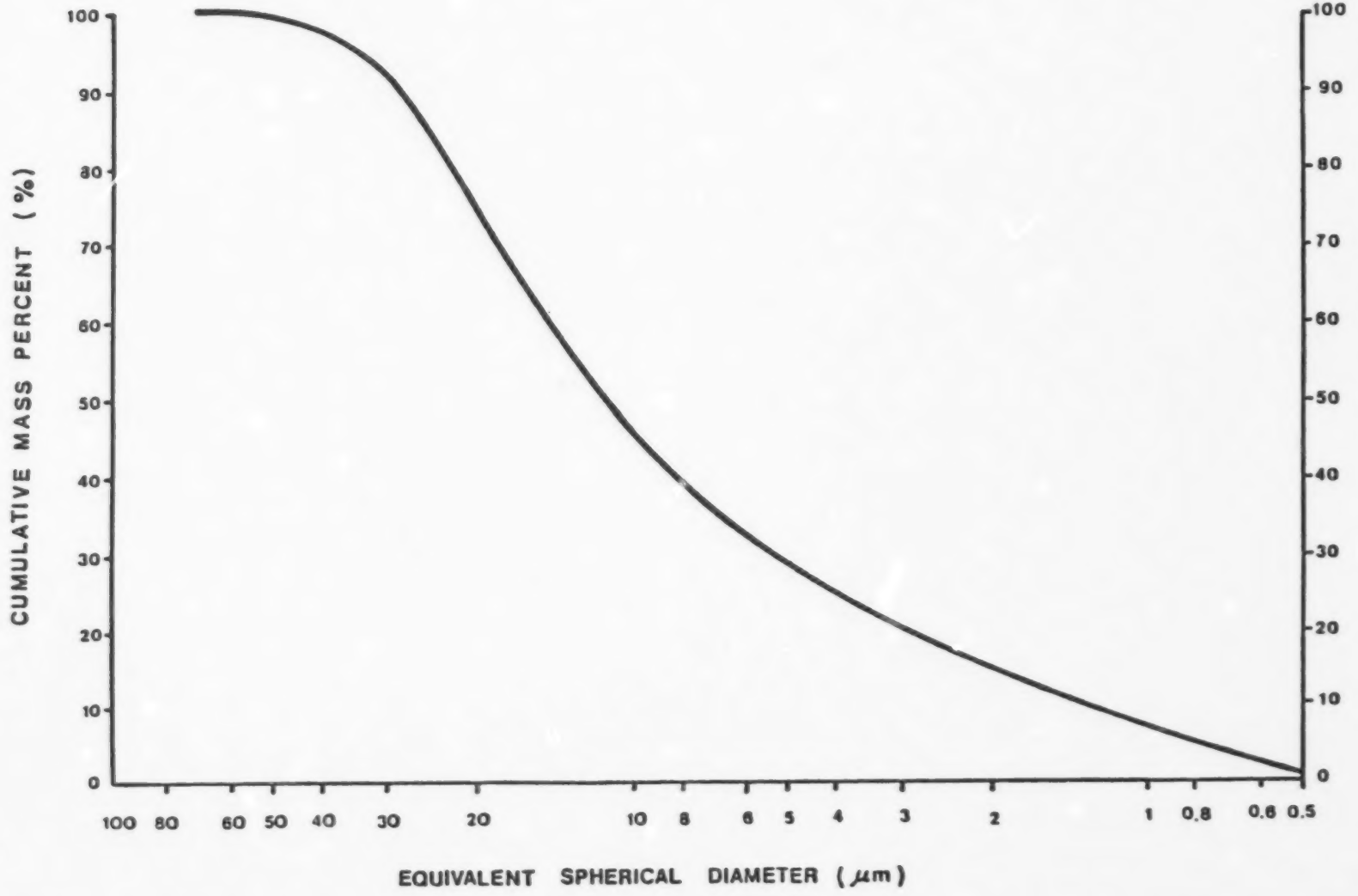
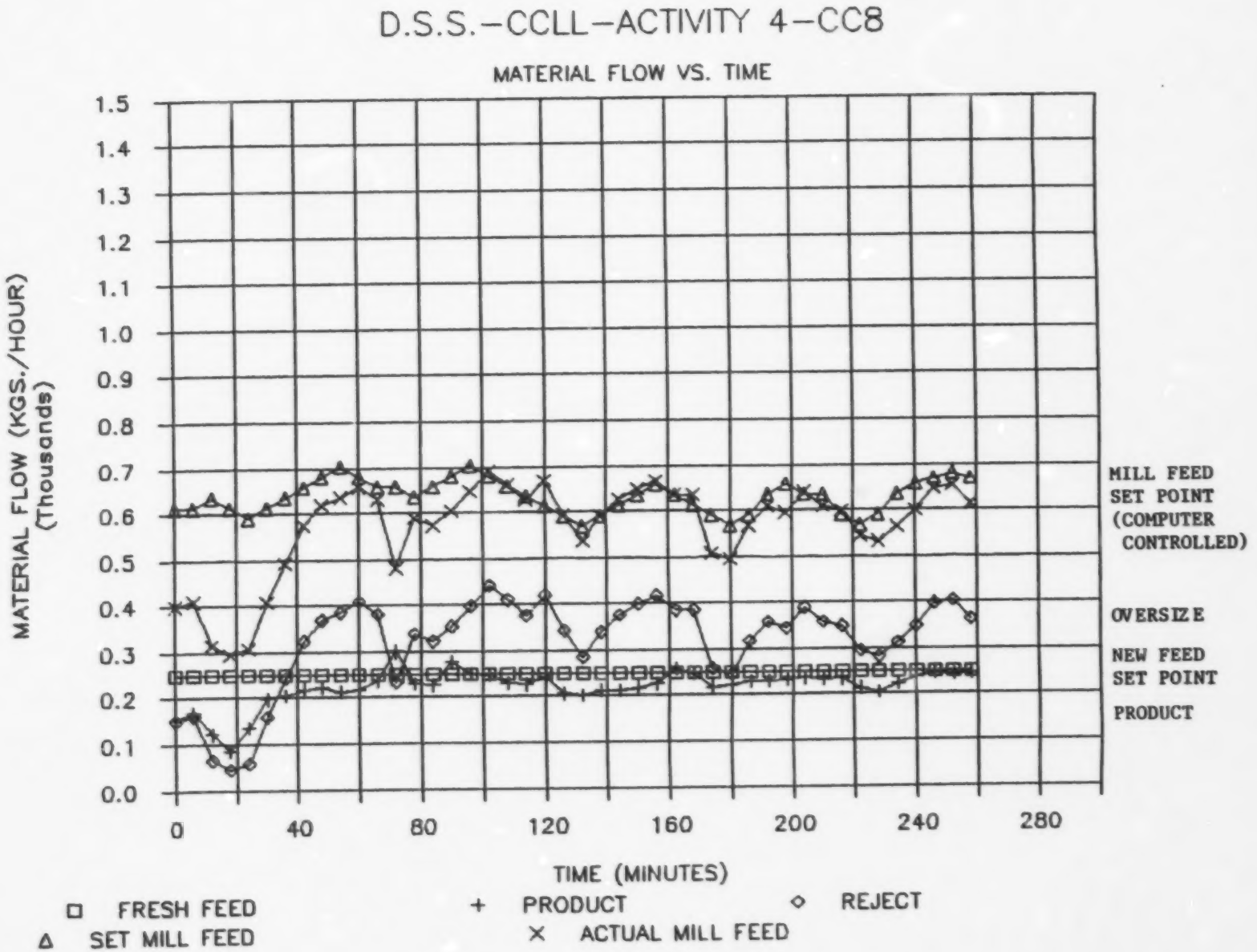


Figure 5.8-F3

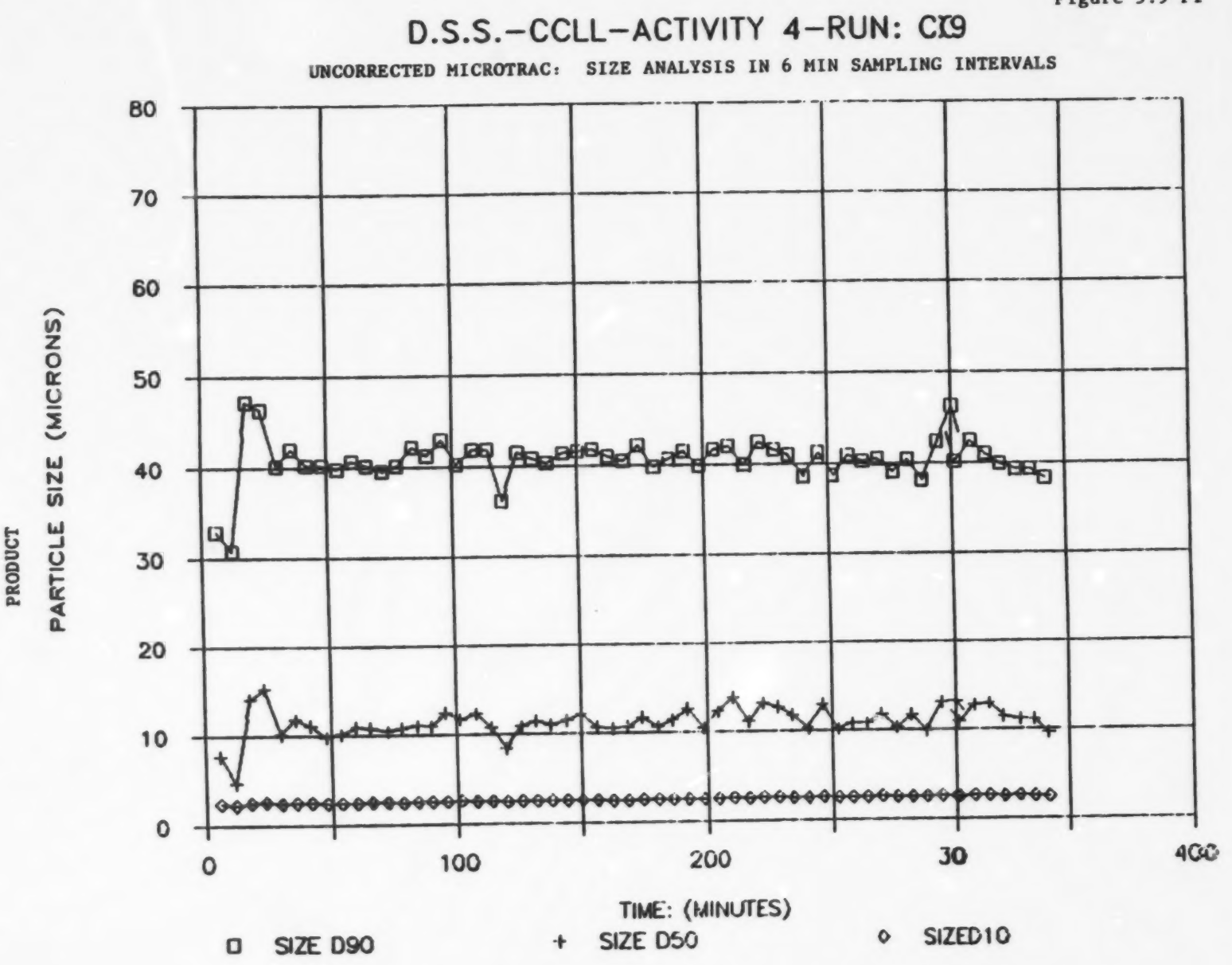

D.S.S.–CCLL–ACTIVITY 4–CC8
MATERIAL FLOW VS. TIME
MATERIAL FLOW (KGS./HOUR)
(Thousands)
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
40
80
120
160
200
240
280
TIME (MINUTES)
MILL FEED SET POINT (COMPUTER CONTROLLED)
OVERSIZE
NEW FEED SET POINT
PRODUCT
□ FRESH FEED
△ SET MILL FEED
+ PRODUCT
× ACTUAL MILL FEED
◇ REJECT

5.9 Run No. 9

Duration:	5 hrs 42 minutes
Feed Rate:	250 kg/hr 30 minutes
	272 kg/hr 30 minutes
	295 kg/hr 60 minutes
	318 kg/hr 66 minutes
	340 kg/hr 54 minutes
	363 kg/hr 60 minutes
	386 kg/hr 42 minutes
D_{90} Target Size:	40 microns
Control:	Computer control
Sample:	Every 6 minutes

The objective of this test was to maximize production of the circuit, while maintaining a constant product size specification. This was achieved, as shown in Figure 5.9-F1 and Figure 5.9-F2. After two hours of operation, the circuit reached its maximum capacity and further increases in feed resulted in an increasing circulating load and a widening gap between the feed set point and production rate (See Figure 5.9-F3). Excess feed was recovered from the mill feed chute and recycled back to the feed hopper. The D90 particle size of the product remained very steady at 40 - 42 microns while the feed in the mill increased from 250 to 386 kg/hr. It should be noted, at each feed race increase, the classifier oversize drops off momentarily, then re-establishes itself at its new level. Figure 5.9-F3 illustrates material flow versus time.

Figure 5.9-F1


D.S.S.-CCLL-ACTIVITY 4-RUN: CX9
UNCORRECTED MICROTRAC: SIZE ANALYSIS IN 6 MIN SAMPLING INTERVALS
PRODUCT
PARTICLE SIZE (MICRONS)
80
70
60
50
40
30
20
10
0
0
100
200
300
400
TIME: (MINUTES)
SIZE D90
SIZE D50
SIZED10

PRODUCT

PARTICLE SIZE DISTRIBUTION

RUN NO. CC 9

Figure 5.9-F2

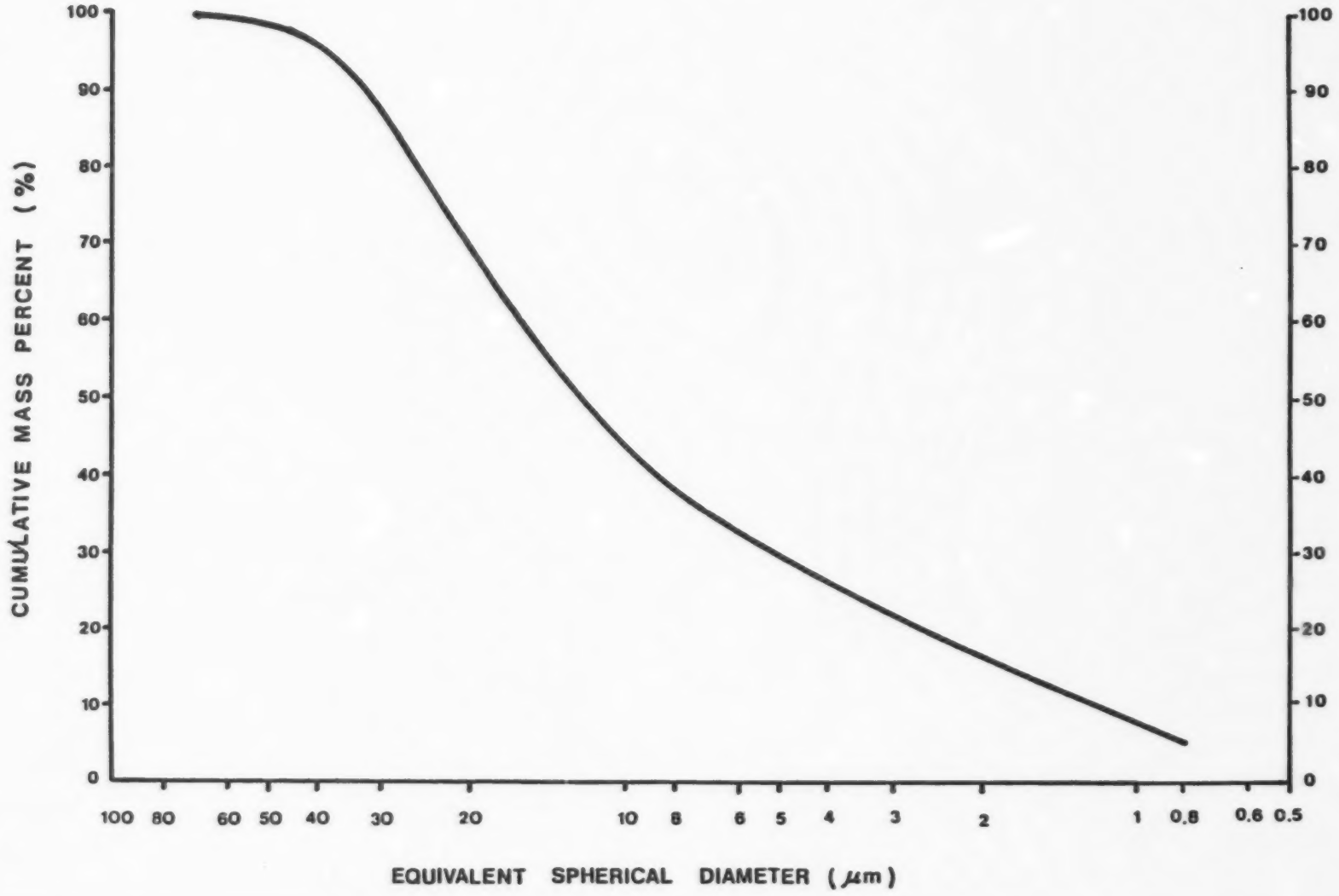
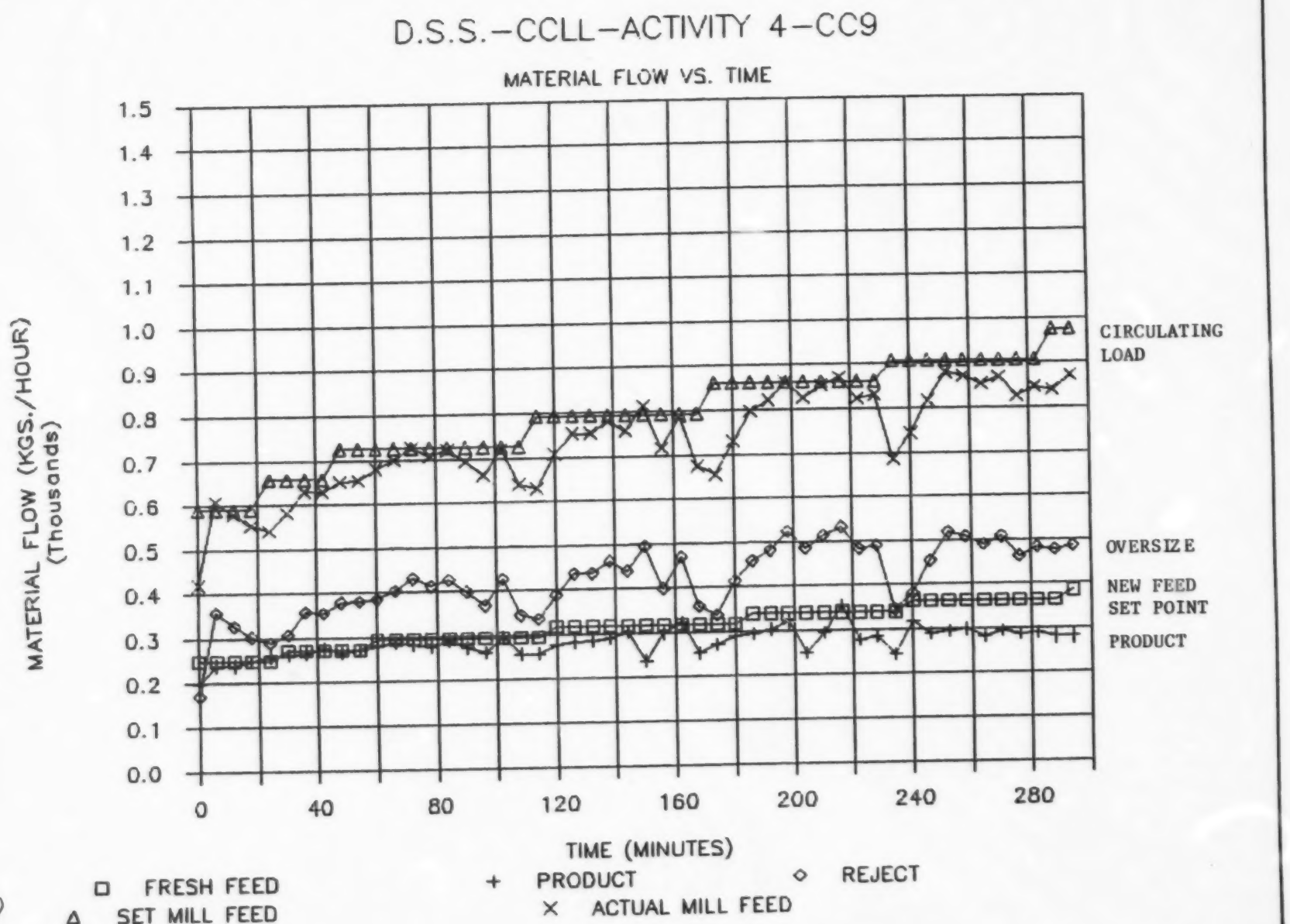


Figure 5.9-F3


D.S.S.–CCLL–ACTIVITY 4–CC9
MATERIAL FLOW VS. TIME
MATERIAL FLOW (KGS./HOUR)
(Thousands)
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
40
80
120
160
200
240
280
TIME (MINUTES)
CIRCULATING LOAD
OVERSIZE
NEW FEED SET POINT
PRODUCT
□ FRESH FEED
△ SET MILL FEED
+ PRODUCT
× ACTUAL MILL FEED
◇ REJECT

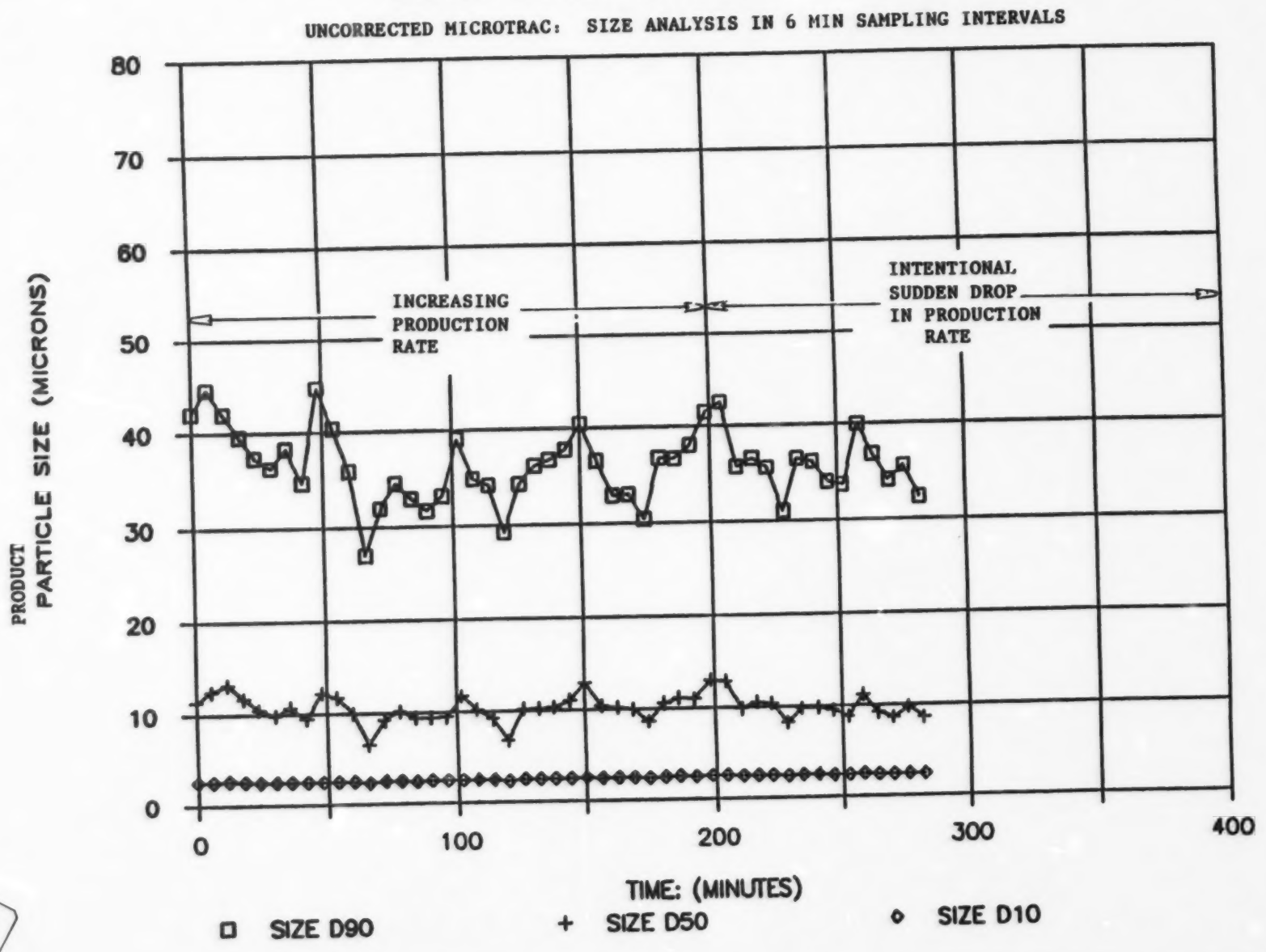
5.10 Run No. 10

Duration:	5 hrs
Feed Rate:	295 kg/hr 60 minutes
	318 kg/hr 30 minutes
	340 kg/hr 30 minutes
	363 kg/hr 30 minutes
	386 kg/hr 60 minutes
	272 kg/hr 90 minutes
D_{90} Target Size:	100% pass 40 microns
Control:	Computer control
Samples:	Every 6 minutes

The feed rate was steadily increased during this test from 295 kg/hr to 386 kg/hr then returned, quickly to 272 kg/hr as illustrated in Figure 5.10-F3. The product specification at 100% passing 40 microns was easily maintained during the adjustments in classifier throughput as shown in Figure 5.10-F1.

Figure 5.10-F1

D.S.S.-CCLL-ACTIVITY 4-RUN: CC10



PRODUCT

Figure 5.10-F2

PARTICLE SIZE DISTRIBUTION

RUN NO. CC 10

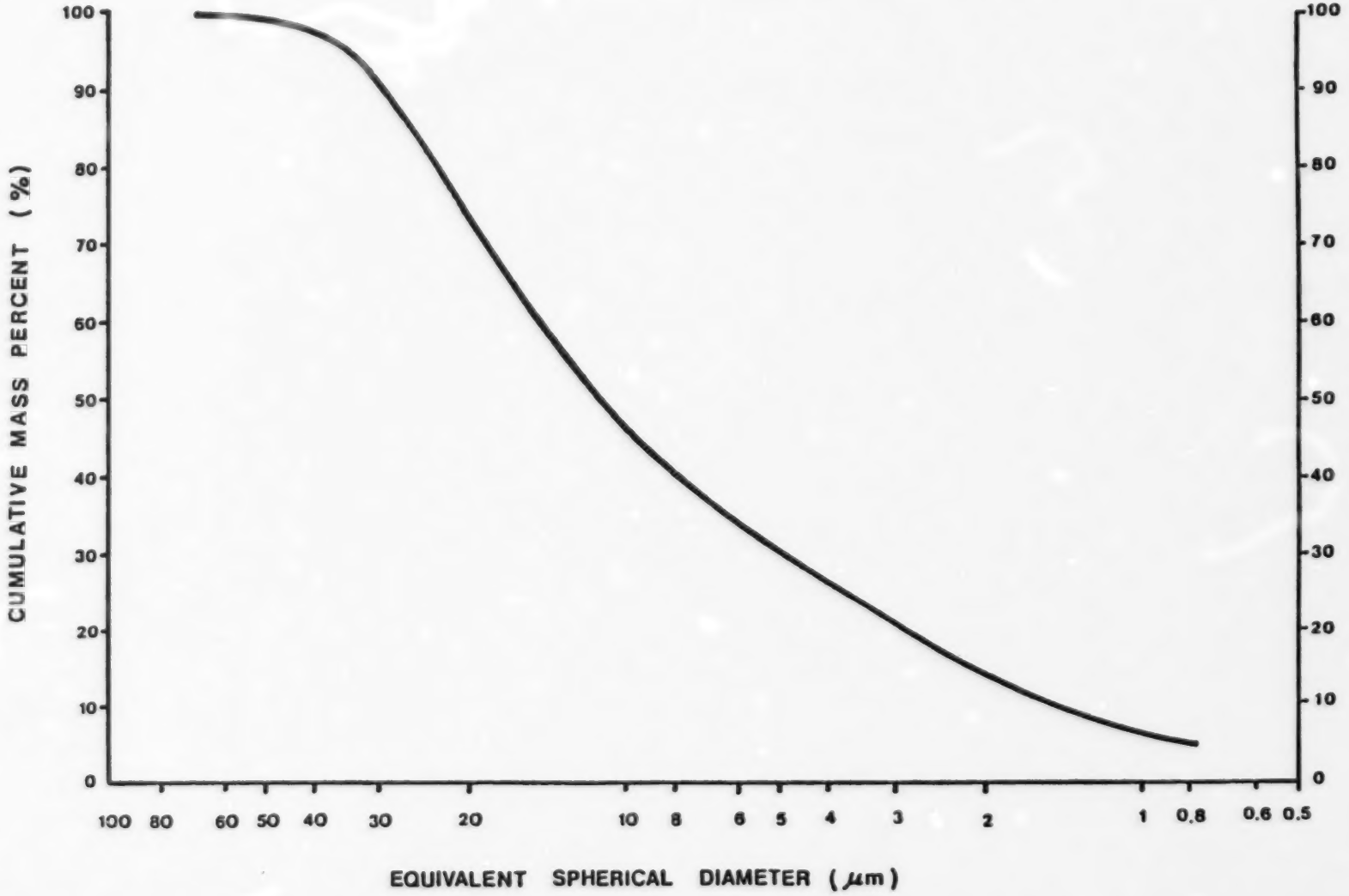
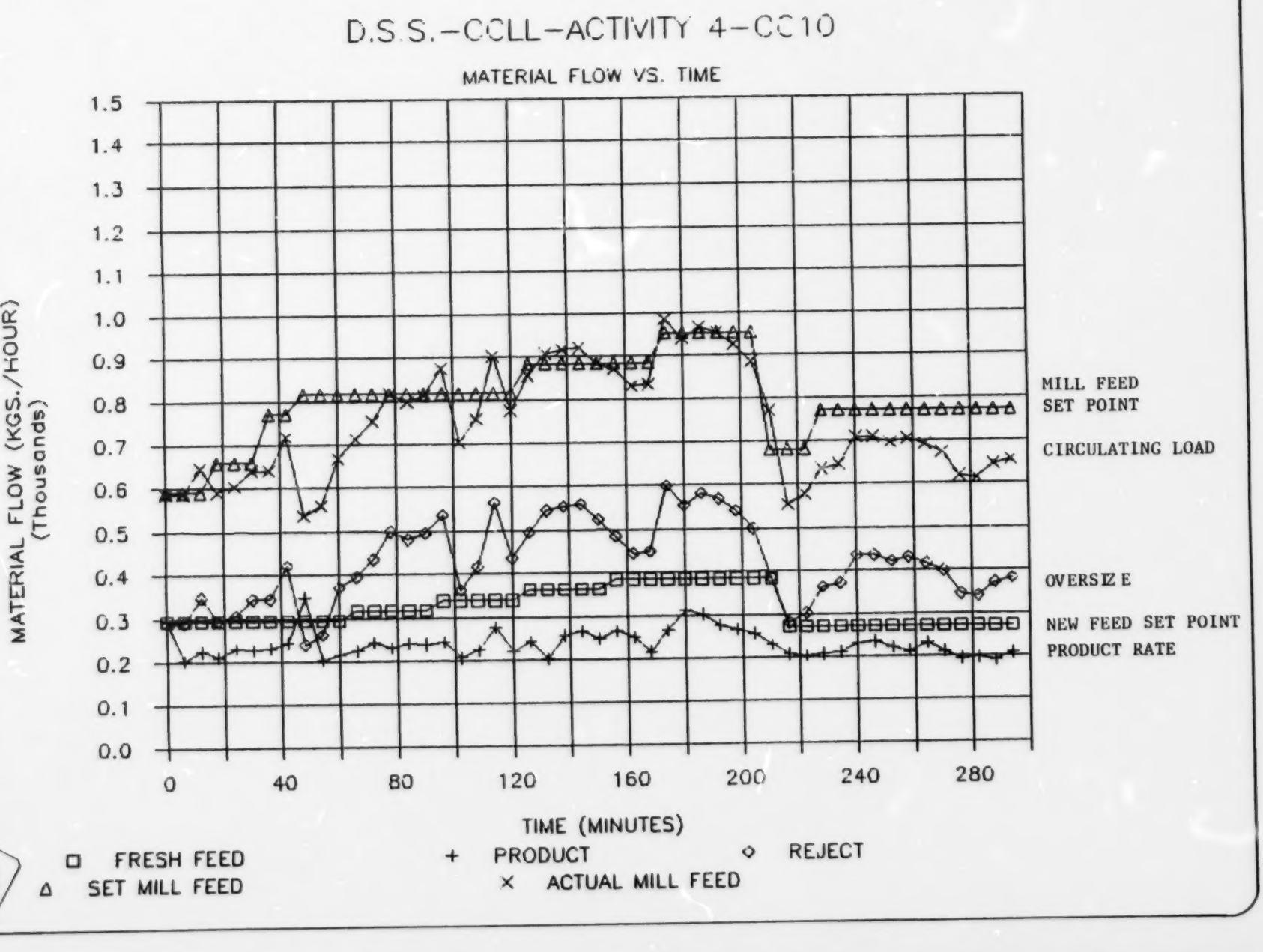


Figure 5.10-F3



5.11 Run No. 11

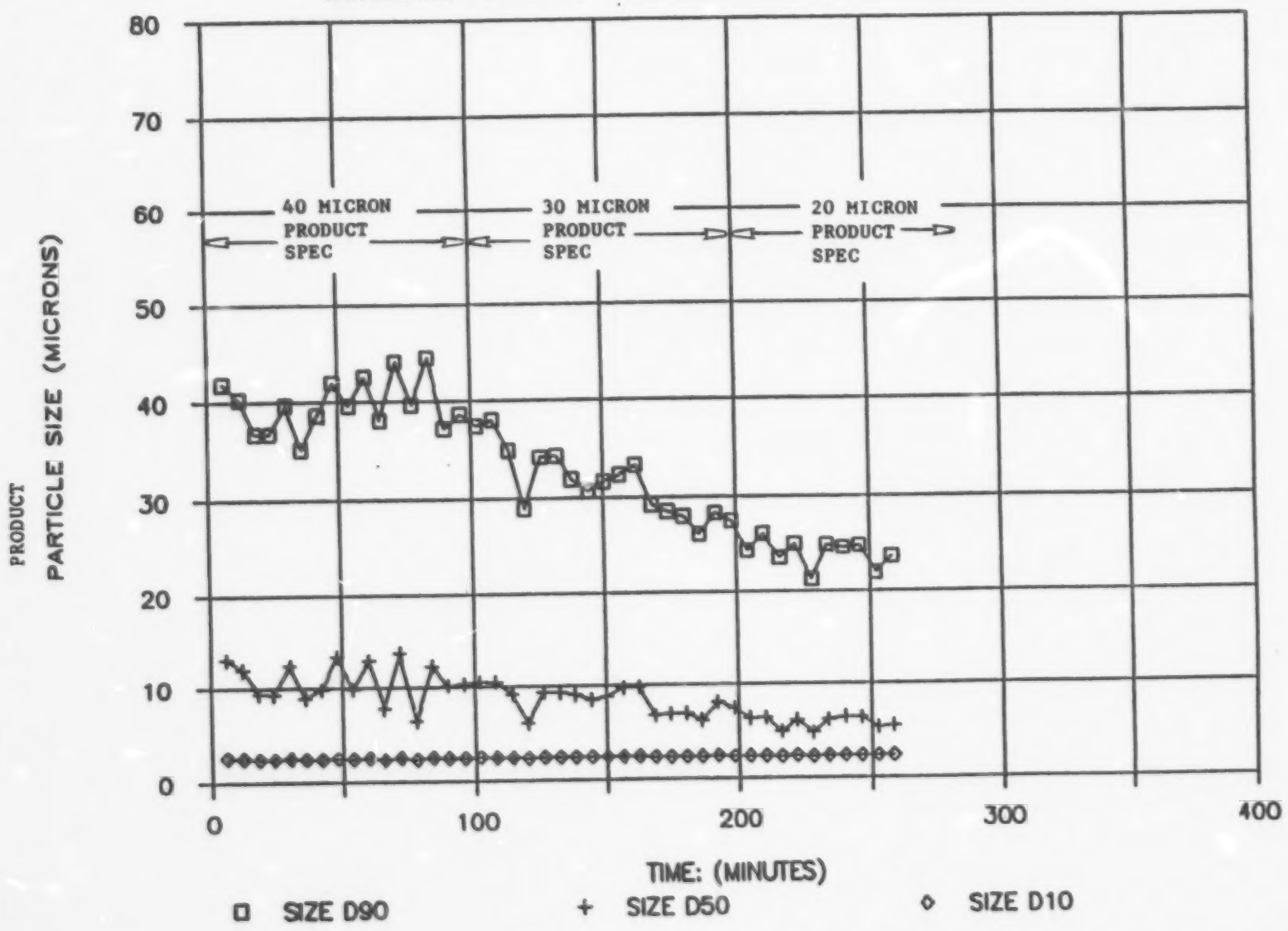
Duration:	4 hrs 30 minutes
Feed Rate:	272 kg/hr
D_{90} Target Size:	40 microns 30 microns 20 microns
Control:	Computer control
Sampling:	Every 6 minutes

For this test, new feed to the mill was kept constant, while product specifications were steadily changed from 40% passing 40 microns to 90% passing 20 microns. Figure 5.11-F1 illustrates the product size versus time and the 90% passing size can clearly be seen dropping from 40 microns to 25 microns. The feed rate was held constant, but the recirculating load increased dramatically at these lower product specifications as illustrated in Figure 5.11-F3. The particle size distribution curve is illustrated in Figure 5.11-F2.

Figure 5.11-F1

D.S.S.-CCLL-ACTIVITY 4-RUN: CC11

UNCORRECTED MICROTRAC: SIZE ANALYSIS IN 6 MIN SAMPLING INTERVALS



PRODUCT

PARTICLE SIZE DISTRIBUTION

RUN NO. CC 11

Figure 5.11-F2

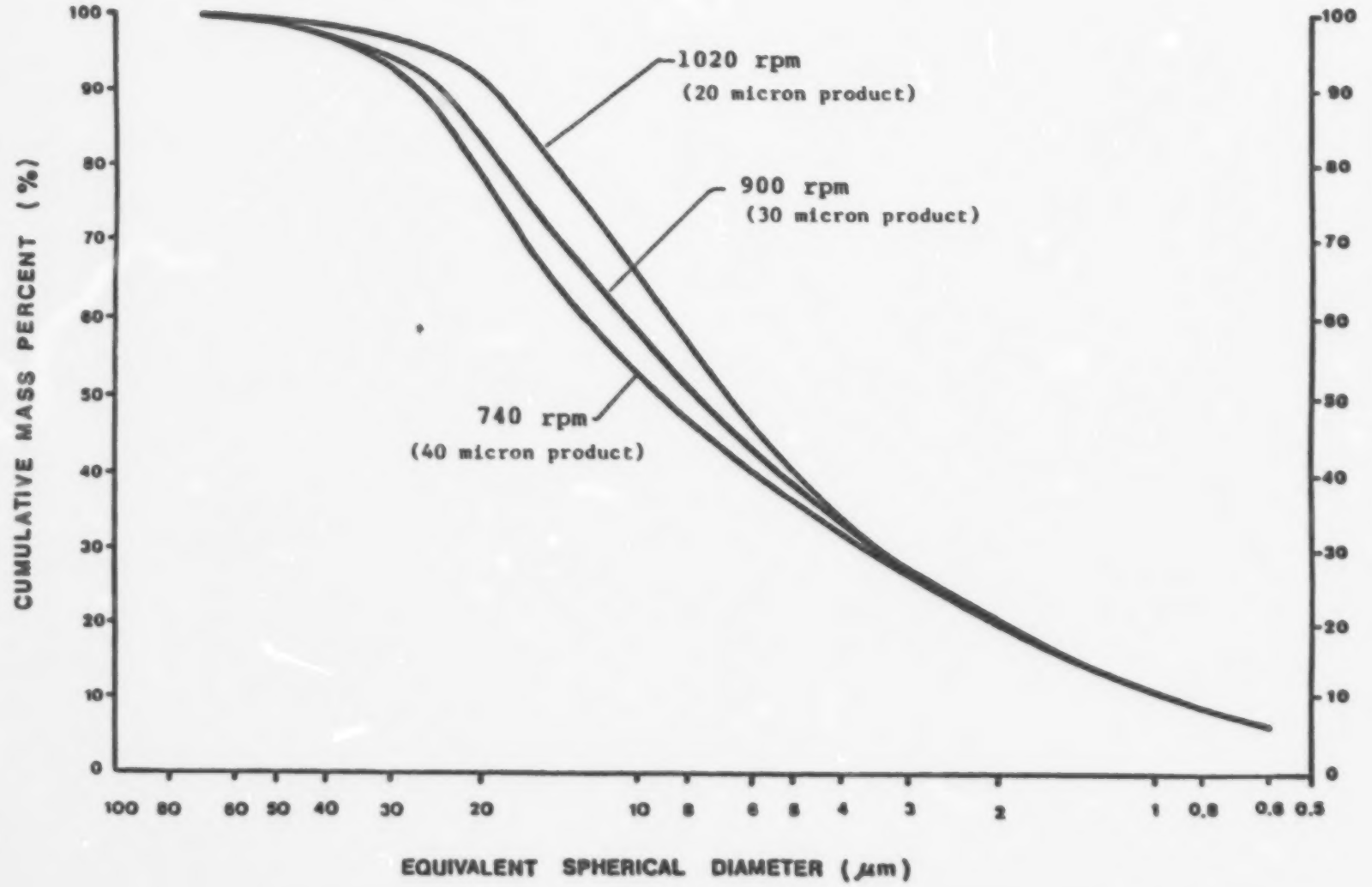
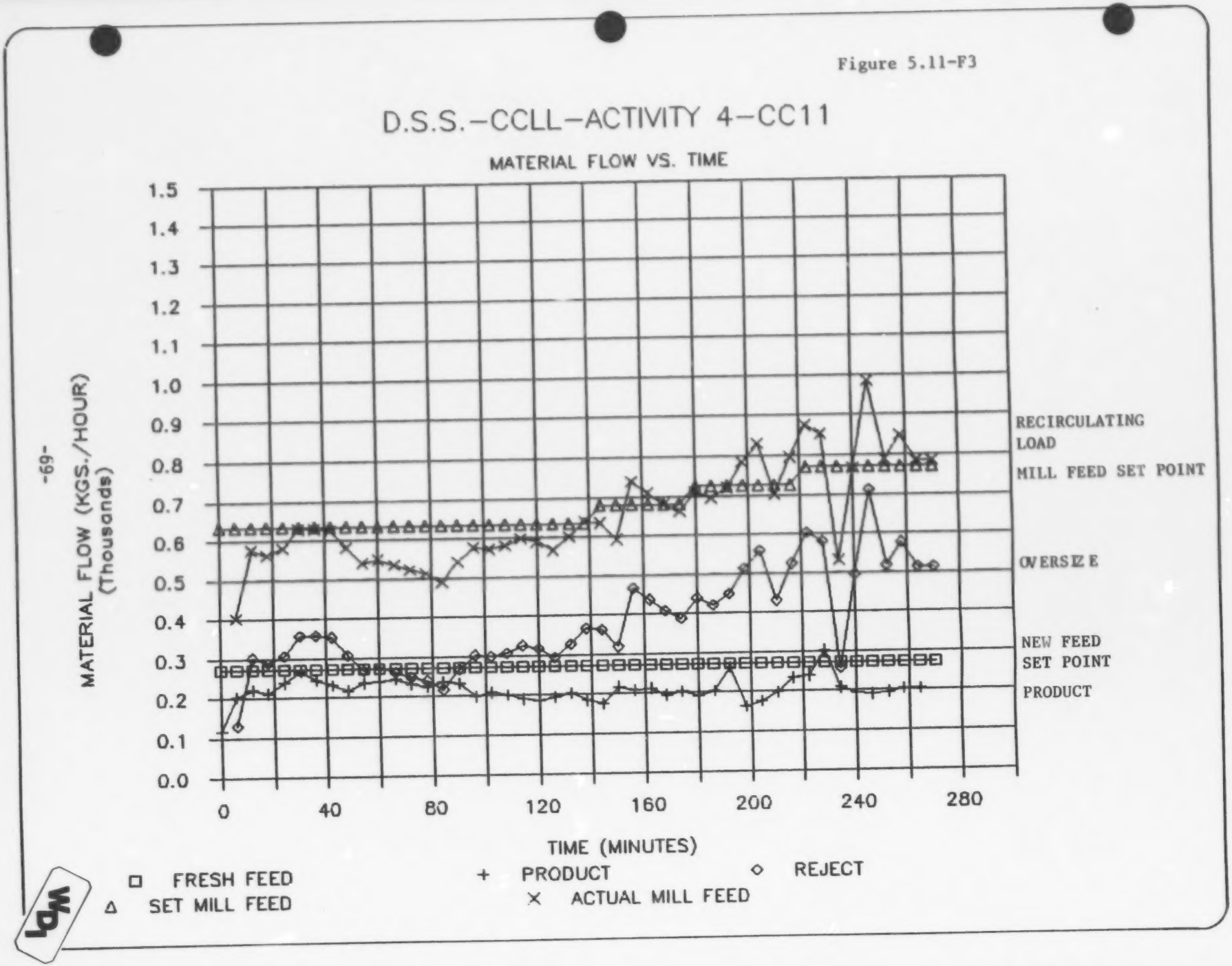


Figure 5.11-F3



5.12 Run No. 12

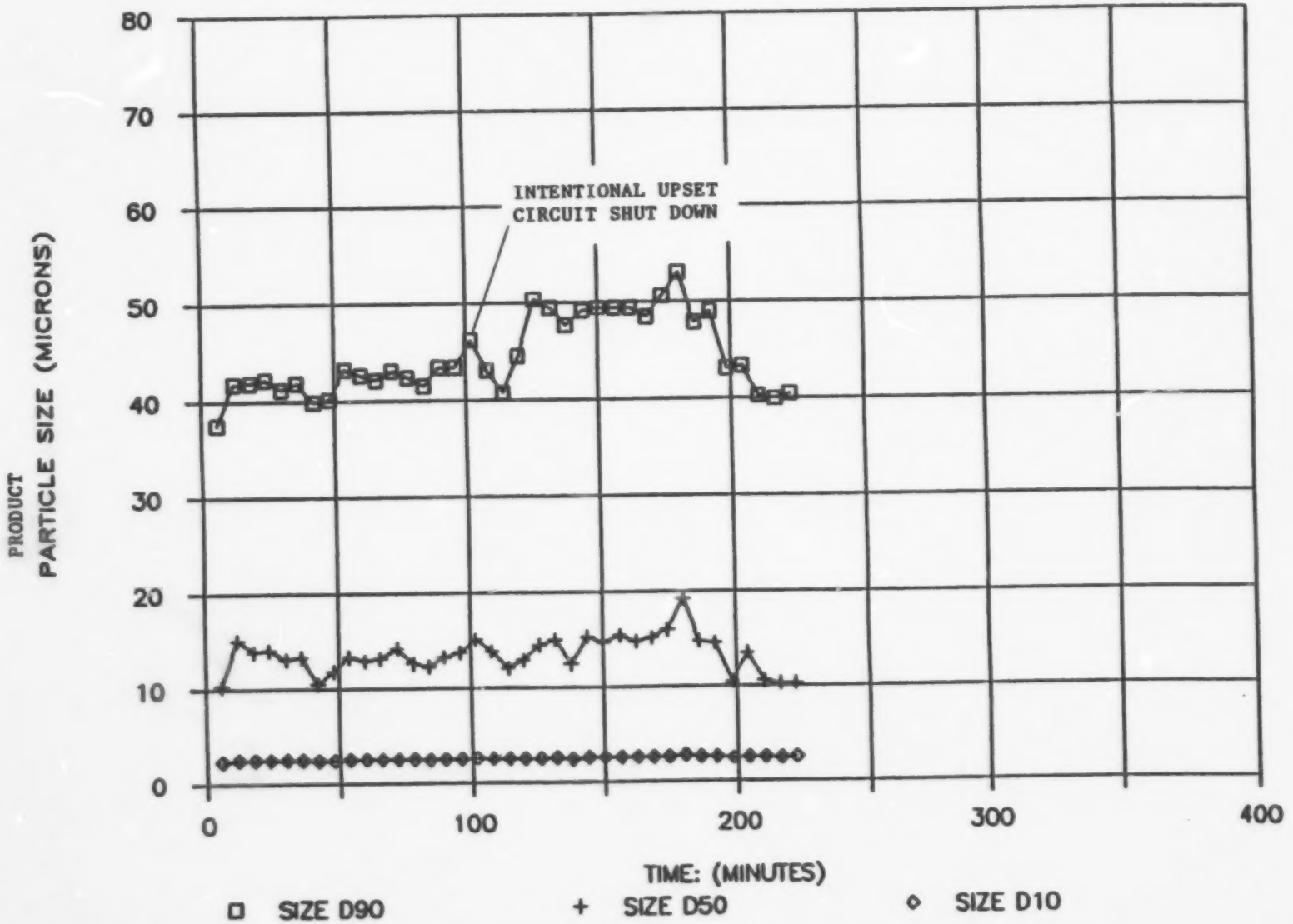
Duration:	4 hours
Feed Rate:	295 kg/hr 2.5 hours 318 kg/hr 1 hour 0 kg/hr 0.5 hours
D_{90} Target Size:	100% 40 microns
Control:	Computer control
Sampling:	Every 6 minutes

The objective of the test was to observe the time required for the computer to re-establish equilibrium after a circuit upset, such as a prolonged shut-down. It was observed that an upset such as a 30-minute shut down had little effect on the time required to bring product quality up to specification with computer control. Figure 5.12-F1 illustrates particle size versus time for Run No. 12. Figure 5.12-F3 illustrates material flow versus time for Run No. 12. The particle size distribution curve is illustrated in Figure 5.12-F2.

Figure 5.12-F1

D.S.S.-CCLL-ACTIVITY 4-RIN: CC12

UNCORRECTED MICROTRAC: SIZE ANALYSIS IN 6 MIN SAMPLING INTERVALS



PRODUCT

PARTICLE SIZE DISTRIBUTION

RUN NO. CC 12

Figure 5.12-F2

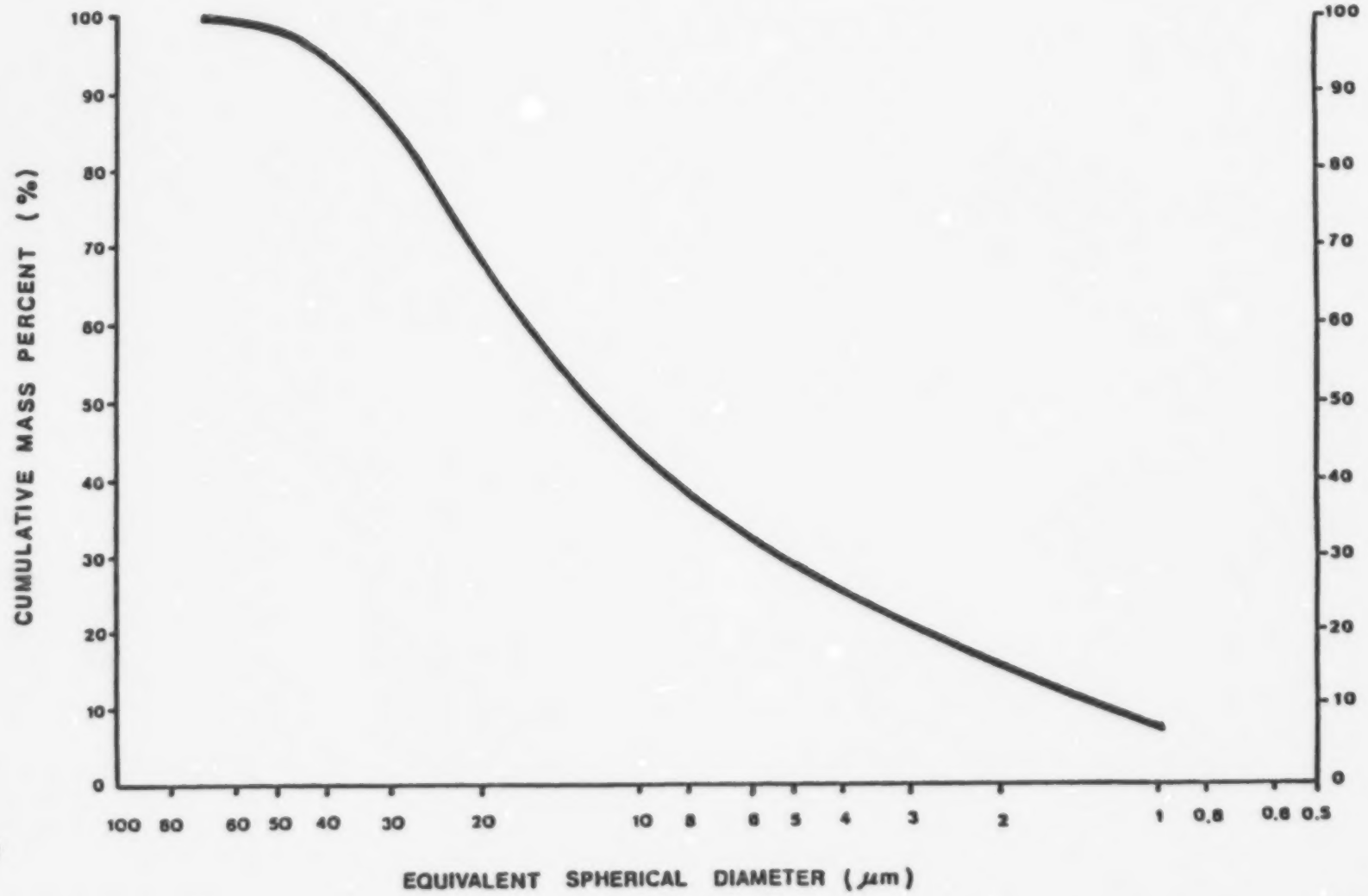
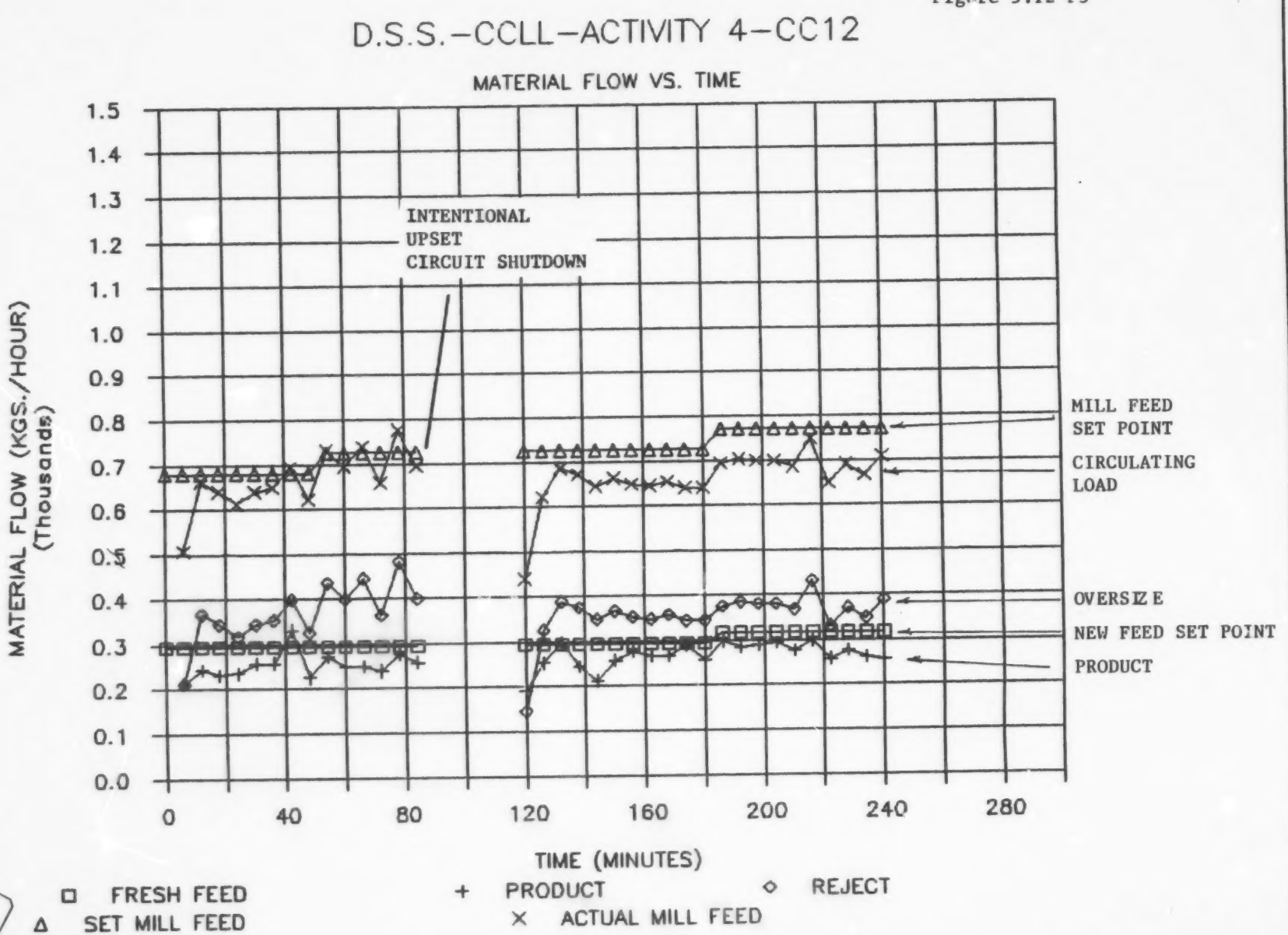


Figure 5.12-F3



6.0 CONCLUSIONS

Based on pilot plant testing completed during Activity 4, the following conclusions have been determined:

1. On-line particle size analysis and computer control of the grinding and classification circuit was beneficial to the operation for the following reasons:

    - o Decreased operator input with circuit control being automatically implemented every six months.
    - o Maintained a constant product size distribution.
    - o Potential of increased production rate as a result of decreased production of off-spec product.
    - o Potential of decreased operating costs per ton of product.

2. On-line particle size analysis was useful to a mill operator in monitoring and controlling the performance of the grinding and classification circuit.

    - o The circuit was readily controlled to a given set point size represented by the D_{90} passing size.
    - o After upsets or shutdowns, the circuit rapidly resumed its normal operation under computer control.
    - o The circuit adjusted to a set point change in size of product required within twenty minutes.
    - o Monitoring of the circulating load was important in the circuit because of the lag time between size set point changes and the stabilizing of the circulating load.

APPENDIX

CCLL ACTIVTY 4
PROJECT NO. 5174
MATERIAL FLOW
C.C. MILL RUN NO. 7
DATE:SEPTEMBER 18,1986

TIME MINUTES	FRESH FEED (lb./hr.)	PRODUCT (lb./hr.)	REJECT (lb./hr.)	SET MILL FEED (lb./hr.)	ACTUAL MILL FEED (lb./hr.)
0	850	430	470	1700	1320
6	850	520	890	1850	1740
12	850	620	815	1850	1665
18	850	510	810	2000	1660
24	850	590	985	2000	1835
30	850	590	1105	2000	1955
36	850	610	1075	2100	1925
42	850	620	1260	2100	2110
48	850	650	1235	2100	2085
54	850	645	1370	2100	2220
60	850	605	1370	2100	2220
66	850	620	1200	2100	2050
72	850	730	1150	2100	2000
78	850	955	1130	2100	1980
84	850	940	910	2100	1760
90	850	750	1100	2100	1950
96	850	610	1260	2100	2110
102	850	560	1850	2100	2700
108					
114	850	460	510	2100	1360
120	850	590	1170	2100	2020
126	850	765	1100	2100	1950
132	850	630	1075	2100	1925
138	850	670	1095	2100	1945
144	850	695	1055	2100	1905
150	850	675	1070	2100	1920
156	850	500	975	2100	1825
162	850	605	1145	2100	1995
168	850	670	1020	2100	1870
174	850	655	950	2100	1800
180	850	650	990	2100	1840
186	850	690	990	2100	1840
192	850	675	1045	2100	1895
198	850	635	905	2100	1755
204	850	670	1040	2100	1890
210	850	665	1005	2100	1855
216	850	650	1060	2100	1910
222	850	655	1020	2100	1870
228	850	685	995	2100	1845
234	850	445	1005	2100	1855
240	850	655	980	2100	1830
246	850	615	975	2100	1825
252	850	590	930	2100	1780
258	850	615	1025	2100	1875
264	850	605	980	2100	1830
270	850	620	975	2100	1825
276	850	560	1000	2100	1850
282	850	710	1000	2100	1850
288	850	635	1035	2100	1885
294	850	695	1130	2100	1980

CCLL ACTIVITY 4
PROJECT NO. 5174
COMPUTER CONTROLLED MILL RUN
RUN #7
SEPTEMBER 18,1986
SAMPLING FREQUENCY: EVERY 6 MINUTES

TIME (MINUTES)	FEED RATE (LBS./HR.	ROTOR SPEED (RPM)	**	MICROTRAC ANALYSIS D90	D50	D10
00:00	850	750	**	40	10	2.5
00:06	850	750	**	?	?	?
00:12	850	750	**	?	?	?
00:18	850	750	**	?	?	?
00:24	850	750	**	?	?	?
00:30	850	750	**	?	?	?
00:36	850	750	**	?	?	?
00:42	850	750	**	?	?	?
00:48	850	750	**	?	?	?
00:54	850	750	**	?	?	?
01:00	850 C.C.		**	40	10	2.5
01:06	850 C.C.		**	?	?	?
01:12	850 C.C.		**	?	?	?
01:18	850 C.C.		**	?	?	?
01:24	850 C.C.		**	?	?	?
01:30	850 C.C.		**	?	?	?
01:36	850 C.C.		**	?	?	?
01:42	850 C.C.		**	?	?	?
01:48	850 C.C.		**	?	?	?
01:54	850 C.C.		**	?	?	?
02:00	850 C.C.		**	?	?	?
02:06	850 C.C.		**	?	?	?
02:12	850 C.C.		**	?	?	?
02:18	850 C.C.		**	?	?	?
02:24	850 C.C.		**	?	?	?
02:30	850 C.C.		**	?	?	?
02:36	850 C.C.		**	?	?	?
02:42	850 C.C.		**	?	?	?
02:48	850 C.C.		**	?	?	?
02:54	850 C.C.		**	?	?	?
03:00	850 C.C.		**	?	?	?
03:06	850 C.C.		**	?	?	?
03:12	850 C.C.		**	?	?	?
03:18	850 C.C.		**	?	?	?
03:24	850 C.C.		**	?	?	?
03:30	850 C.C.		**	?	?	?
03:36	850 C.C.		**	?	?	?
03:42	850 C.C.		**	?	?	?
03:48	850 C.C.		**	?	?	?
03:54	850 C.C.		**	?	?	?
04:00	850 C.C.		**	?	?	?
04:06	850 C.C.		**	?	?	?
04:12	850 C.C.		**	?	?	?
04:18	850 C.C.		**	?	?	?
04:24	850 C.C.		**	?	?	?
04:30	850 C.C.		**	?	?	?
04:36	850 C.C.		**	?	?	?
04:42	850 C.C.		**	?	?	?
04:48	850 C.C.		**	?	?	?
04:54	850 C.C.		**	?	?	?
05:00	850 C.C.		**	?	?	?

D90 RAW DATA

TIME (MINUTES)	#1 D90 (MICRONS)	#2 D90 (MICRONS)	#3 D90 (MICRONS)	#4 D90 (MICRONS)	#5 D90 (MICRONS)	STAN. DEV. (MICRONS)
00:00						0.00
00:06	36.54	34.36	38.08	37.63	38.67	1.52
00:12	35.59	35.76	35.66	34.5	33.23	0.97
00:18	39.33	39.48	39.52	39.11	40.88	0.62
00:24	26.37	28.02	23.8	28.52	28.87	1.87
00:30	30.78	30.01	30.2	30.33	32.63	0.95
00:36	21.93	25.66	22.08	25.26	25.98	1.79
00:42	29.83	30.2	31.01	30.11	32.39	0.93
00:48	29.53	30.61	30.21	29.99	28.92	0.58
00:54	35.29	33.26	31.73	34.56	33.54	1.21
01:00	30.43	30.92	30.83	33.26	32.24	1.06
01:06	29.85	30.56	30.28	29.85	30.45	0.30
01:12	31.47	28.96	28.39	31.83	29.81	1.35
01:18	47.23	47.56	48.33	49.47	48.53	0.79
01:24	52.21	49.79	52.35	50.21	50.03	1.12
01:30	35.13	34.43	35.16	35.45	34.61	0.38
01:36	36.93	33.31	35.48	38.68	37.57	1.86
01:42	22.89	27	26.73	23.62	26.02	1.68
01:48	28.44	27.91	27.99	27.53	28.44	0.35
01:54	34.97	34.25	33.42	34.25	34.02	0.50
02:00	36.02	35.14	32.63	35.32	35.85	1.22
02:06	29.68	29.99	30.13	29.6	31.96	0.87
02:12	40.07	36.74	37.88	38.28	37.99	1.08
02:18	42.66	45.16	41.92	43.39	41.84	1.22
02:24	44.94	45.49	43.67	42.7	44.48	0.98
02:30	47.09	45.25	45.09	44.78	47.37	1.09
02:36	38.56	41.13	40.72	42.22	44.57	1.97
02:42	40.51	39.14	39.48	42.61	38.71	1.39
02:48	42.79	44.58	45.11	44.17	45.43	0.92
02:54	45.11	40.76	45.24	43.97	45.1	1.70
03:00	43.72	41.44	39.6	44.4	41.44	1.73
03:06	41.68	45	41.69	44.03	41.9	1.39
03:12	43.2	43.66	44.03	43.85	42.69	0.48
03:18	47.32	44.19	42.81	44.67	45.01	1.47
03:24	41.45	40.49	39.69	38.53	39.05	1.04
03:30	43.24	40.9	44.09	44.58	46.91	1.95
03:36	43.75	41.51	43.45	44.95	44.3	1.16
03:42	42.68	42.68	43.76	40.71	40.5	1.26
03:48	43.59	42.68	44.92	45.09	45.47	1.05
03:54	46.14	44.49	43.91	46.49	48.47	1.61
04:00	39.1	39.25	44.21	42.07	41.44	1.90
04:06	41.21	44.12	41.34	40.91	43.05	1.25
04:12	36.96	38.13	37.87	35.6	41.93	2.11
04:18	40.95	42.45	40.07	42.22	44.38	1.47
04:24	42.52	38.28	41.74	41.54	40.78	1.46
04:30	42.47	43.61	43.5	43.16	42.71	0.44
04:36	42.98	40.87	41.03	42.15	41.42	0.78
04:42	28.98	23.92	28.69	19.11	24.67	3.62
04:48	38.96	38.24	41.02	38.91	37.67	1.13
04:54	40.72	39.5	44.48	40.67	40.53	1.71
05:00						

D90 RAW DATA

TIME (MINUTES)	#1 D90 (MICRONS)	#2 D90 (MICRONS)	#3 D90 (MICRONS)	#4 D90 (MICRONS)	#5 D90 (MICRONS)	STAN. DEV. (MICRONS)
00:00						0.00
00:06	36.54	34.36	38.08	37.63	38.67	1.52
00:12	35.59	35.76	35.66	34.5	33.23	0.97
00:18	39.33	39.48	39.52	39.11	40.88	0.62
00:24	26.37	28.02	23.8	28.52	28.87	1.87
00:30	30.78	30.01	30.2	30.33	32.63	0.95
00:36	21.93	25.66	22.08	25.26	25.98	1.79
00:42	29.83	30.2	31.01	30.11	32.39	0.93
00:48	29.53	30.61	30.21	29.99	28.92	0.58
00:54	35.29	33.26	31.73	34.56	33.54	1.21
01:00	30.43	30.92	30.83	33.26	32.24	1.06
01:06	29.85	30.56	30.28	29.85	30.45	0.30
01:12	31.47	28.96	28.39	31.83	29.81	1.35
01:18	47.23	47.56	48.33	49.47	48.53	0.79
01:24	52.21	49.79	52.35	50.21	50.03	1.12
01:30	35.13	34.43	35.16	35.45	34.61	0.38
01:36	36.93	33.31	35.48	38.68	37.57	1.86
01:42	22.89	27	26.73	23.62	26.02	1.68
01:48	28.44	27.91	27.99	27.53	28.44	0.35
01:54	34.97	34.25	33.42	34.25	34.02	0.50
02:00	36.02	35.14	32.63	35.32	35.85	1.22
02:06	29.68	29.99	30.13	29.6	31.96	0.87
02:12	40.07	36.74	37.88	38.28	37.99	1.08
02:18	42.66	45.16	41.92	43.39	41.84	1.22
02:24	44.94	45.49	43.67	42.7	44.48	0.98
02:30	47.09	45.25	45.09	44.78	47.37	1.09
02:36	38.56	41.13	40.72	42.22	44.57	1.97
02:42	40.51	39.14	39.48	42.61	38.71	1.39
02:48	42.79	44.58	45.11	44.17	45.43	0.92
02:54	45.11	40.76	45.24	43.97	45.1	1.70
03:00	43.72	41.44	39.6	44.4	41.44	1.73
03:06	41.68	45	41.69	44.03	41.9	1.39
03:12	43.2	43.66	44.03	43.85	42.69	0.48
03:18	47.32	44.19	42.81	44.67	45.01	1.47
03:24	41.45	40.49	39.09	38.53	39.05	1.04
03:30	43.24	40.9	44.09	44.58	46.91	1.95
03:36	43.75	41.51	43.45	44.95	44.3	1.16
03:42	42.68	42.68	43.76	40.71	40.5	1.26
03:48	43.59	42.68	44.92	45.09	45.47	1.05
03:54	46.14	44.49	43.91	46.49	48.47	1.61
04:00	39.1	39.25	44.21	42.07	41.44	1.90
04:06	41.21	44.12	41.34	40.91	43.05	1.25
04:12	36.96	38.13	37.87	35.6	41.93	2.11
04:18	40.95	42.45	40.07	42.22	44.38	1.47
04:24	42.52	38.28	41.74	41.54	40.78	1.46
04:30	42.47	43.61	43.5	43.16	42.71	0.44
04:36	42.98	40.87	41.03	42.15	41.42	0.78
04:42	28.98	23.92	28.69	19.11	24.67	3.62
04:48	38.96	38.24	41.02	38.91	37.67	1.13
04:54	40.72	39.5	44.48	40.67	40.53	1.71
05:00						

D50 RAW DATA

TIME (MINUTES)	#1 D50 (MICRONS)	#2 D50 (MICRONS)	#3 D50 (MICRONS)	#4 D50 (MICRONS)	#5 D50 (MICRONS)	STAN. DEV. (MICRONS)
00:00						0.00
00:06	10.78	9.53	10.59	10.38	10.58	0.44
00:12	9.06	9.02	8.94	8.88	9.04	0.07
00:18	12.13	11.27	12.1	11.63	12.15	0.35
00:24	6.92	6.9	6.67	7.34	7.36	0.27
00:30	8.47	8.35	8.45	8.65	8.66	0.12
00:36	6.36	6.81	6.42	6.66	6.88	0.21
00:42	8.54	8.66	8.5	8.45	8.87	0.15
00:48	8.5	8.78	8.7	8.72	8.79	0.10
00:54	10.34	9.92	9.73	9.97	9.62	0.25
01:00	9.17	9.42	9.23	9.57	9.64	0.18
01:06	9.63	9.58	9.71	9.45	9.91	0.15
01:12	8.3	7.85	8.14	8.52	8.16	0.22
01:18	14.36	14.4	14.33	14.68	14.48	0.13
01:24	15.37	14.76	15.27	15.26	15.27	0.22
01:30	9.71	9.32	9.54	9.48	9.45	0.13
01:36	10.01	9.65	9.89	9.8	10.7	0.36
01:42	7.39	8.03	8.07	7.51	8	0.29
01:48	9.38	8.95	9.46	9.08	9.25	0.19
01:54	10.63	10.53	10.32	11.36	10.63	0.35
02:00	10.72	10.76	10.23	10.93	10.59	0.23
02:06	8.89	9.15	9	9	9.3	0.14
02:12	10.32	10.23	10.3	10.27	10.32	0.03
02:18	12.12	11.99	12.39	12.7	12.87	0.33
02:24	11.35	11.81	12.2	11.77	12.08	0.29
02:30	13.42	12.92	13.03	13.02	13.41	0.21
02:36	10.44	10.78	10.83	11.1	10.81	0.21
02:42	9.87	9.57	9.96	10.03	10.08	0.18
02:48	11.76	12.07	12.09	12.03	12.11	0.13
02:54	11.19	10.52	10.85	11.31	11.66	0.39
03:00	10.93	11.5	11.07	11.06	11.14	0.19
03:06	11.39	11.35	11.09	11.45	11.09	0.15
03:12	10.75	10.84	10.32	10.63	11.02	0.23
03:18	12.12	11.86	11.88	12.44	11.65	0.27
03:24	9.31	9.08	9.3	9.3	9.1	0.10
03:30	11.63	11.62	11.15	11.83	12.46	0.42
03:36	11.67	11.43	11.15	11.74	11.75	0.23
03:42	9.19	8.93	9.14	8.91	9.13	0.12
03:48	11.96	12.08	11.92	12.25	12.28	0.15
03:54	12.49	12.61	13	12.63	12.91	0.19
04:00	9.23	9.33	9.46	9.56	9.76	0.18
04:06	9.96	10.24	10.19	9.91	10.3	0.16
04:12	8.15	8.18	8.08	8.13	8.6	0.19
04:18	9.86	10.28	10.55	10.24	10.41	0.23
04:24	9.55	9.24	9.55	9.3	9.23	0.15
04:30	10.7	10.34	10.58	11.31	11.26	0.38
04:36	9.82	9.73	9.91	10.35	10.15	0.23
04:42	5.22	5.19	5.28	4.86	5.24	0.15
04:48	9.84	9.69	9.79	10.05	9.76	0.12
04:54	8.66	8.76	9.21	8.9	8.99	0.19
05:00						

D10 RAW DATA

TIME (MINUTES)	#1 D10 (MICRONS)	#2 D10 (MICRONS)	#3 D10 (MICRONS)	#4 D10 (MICRONS)	#5 D10 (MICRONS)	STAN. DEV. (MICRONS)
00:00						0.00
00:06	2.45	2.44	2.47	2.48	2.46	0.01
00:12	2.39	2.4	2.39	2.38	2.38	0.01
00:18	2.46	2.47	2.48	2.49	2.51	0.02
00:24	2.32	2.33	2.31	2.33	2.33	0.01
00:30	2.36	2.35	2.36	2.37	2.38	0.01
00:36	2.3	2.32	2.31	2.32	2.33	0.01
00:42	2.37	2.38	2.39	2.39	2.4	0.01
00:48	2.38	2.39	2.4	2.39	2.41	0.01
00:54	2.43	2.43	2.42	2.44	2.43	0.01
01:00	2.43	2.43	2.42	2.42	2.43	0.00
01:06	2.43	2.42	2.45	2.45	2.44	0.01
01:12	2.38	2.36	2.38	2.39	2.37	0.01
01:18	2.56	2.59	2.58	2.58	2.62	0.02
01:24	2.64	2.64	2.62	2.65	2.63	0.01
01:30	2.45	2.43	2.45	2.46	2.46	0.01
01:36	2.45	2.46	2.44	2.46	2.45	0.01
01:42	2.36	2.39	2.38	2.37	2.38	0.01
01:48	2.43	2.43	2.46	2.43	2.46	0.01
01:54	2.47	2.46	2.49	2.47	2.47	0.01
02:00	2.47	2.52	2.48	2.49	2.48	0.02
02:06	2.41	2.41	2.4	2.41	2.41	0.00
02:12	2.45	2.45	2.47	2.46	2.47	0.01
02:18	2.53	2.54	2.55	2.54	2.54	0.01
02:24	2.5	2.49	2.49	2.5	2.48	0.01
02:30	2.52	2.53	2.53	2.55	2.56	0.01
02:36	2.45	2.48	2.47	2.49	2.47	0.01
02:42	2.44	2.44	2.43	2.46	2.45	0.01
02:48	2.53	2.5	2.51	2.51	2.53	0.01
02:54	2.5	2.47	2.48	2.49	2.49	0.01
03:00	2.46	2.48	2.48	2.47	2.5	0.01
03:06	2.49	2.51	2.49	2.47	2.47	0.01
03:12	2.44	2.46	2.46	2.46	2.46	0.01
03:18	2.51	2.51	2.51	2.54	2.51	0.01
03:24	2.38	2.4	2.36	2.4	2.39	0.01
03:30	2.49	2.5	2.48	2.51	2.5	0.01
03:36	2.5	2.49	2.5	2.51	2.51	0.01
03:42	2.38	2.36	2.38	2.37	2.38	0.01
03:48	2.47	2.5	2.49	2.49	2.5	0.01
03:54	2.51	2.51	2.54	2.53	2.55	0.02
04:00	2.42	2.41	2.41	2.41	2.42	0.00
04:06	2.42	2.4	2.41	2.41	2.42	0.01
04:12	2.35	2.35	2.35	2.34	2.35	0.00
04:18	2.43	2.43	2.42	2.41	2.42	0.01
04:24	2.38	2.36	2.37	2.37	2.37	0.01
04:30	2.44	2.44	2.45	2.45	2.45	0.00
04:36	2.41	2.4	2.4	2.44	2.41	0.01
04:42	2.24	2.24	2.25	2.22	2.25	0.01
04:48	2.42	2.42	2.4	2.45	2.44	0.02
04:54	2.36	2.37	2.38	2.38	2.39	0.01
05:00						

ACTUAL OPERATION

TIME (MINUTES)	FEED RATE (LBS/HR.)	ROTOR SPEED (RPM)	AVERAGE D90 (MICRONS)	MICROTRAC ANALYSIS AVERAGE D50 (MICRONS)	AVERAGE D10 (MICRONS)
00:00	850	750			
00:06	850	750	37.1	10.4	2.5
00:12	850	750	34.9	9.0	2.4
00:18	850	750	39.7	11.9	2.5
00:24	850	750	27.1	7.0	2.3
00:30	850	750	30.8	8.5	2.4
00:36	850	750	24.2	6.6	2.3
00:42	850	750	30.7	8.6	2.4
00:48	850	750	29.9	8.7	2.4
00:54	850	750	33.7	9.9	2.4
01:00	850 C.C.		31.5	9.4	2.4
01:06	850 C.C.		30.2	9.7	2.4
01:12	850 C.C.		30.1	8.2	2.4
01:18	850 C.C.		48.2	14.5	2.6
01:24	850 C.C.		50.9	15.2	2.6
01:30	850 C.C.		35.0	9.5	2.5
01:36	850 C.C.		36.4	10.0	2.5
01:42	850 C.C.		25.3	7.8	2.4
01:48	850 C.C.		28.1	9.2	2.4
01:54	850 C.C.		34.2	10.7	2.5
02:00	850 C.C.		35.0	10.6	2.5
02:06	850 C.C.		30.3	9.1	2.4
02:12	850 C.C.		38.2	10.3	2.5
02:18	850 C.C.		43.0	12.4	2.5
02:24	850 C.C.		44.3	11.8	2.5
02:30	850 C.C.		45.9	13.2	2.5
02:36	850 C.C.		41.4	10.8	2.5
02:42	850 C.C.		40.1	9.9	2.4
02:48	850 C.C.		44.4	12.0	2.5
02:54	850 C.C.		44.0	11.1	2.5
03:00	850 C.C.		42.1	11.1	2.5
03:06	850 C.C.		42.9	11.3	2.5
03:12	850 C.C.		43.5	10.7	2.5
03:18	850 C.C.		44.8	12.0	2.5
03:24	850 C.C.		39.8	9.2	2.4
03:30	850 C.C.		43.9	11.7	2.5
03:36	850 C.C.		43.6	11.5	2.5
03:42	850 C.C.		42.1	9.1	2.4
03:48	850 C.C.		44.4	12.1	2.5
03:54	850 C.C.		45.9	12.7	2.5
04:00	850 C.C.		41.2	9.5	2.4
04:06	850 C.C.		42.1	10.1	2.4
04:12	850 C.C.		38.1	8.2	2.3
04:18	850 C.C.		42.0	10.3	2.4
04:24	850 C.C.		41.0	9.4	2.4
04:30	850 C.C.		43.1	10.8	2.4
04:36	850 C.C.		41.7	10.0	2.4
04:42	850 C.C.		25.1	5.2	2.2
04:48	850 C.C.		39.0	9.8	2.4
04:54	850 C.C.		41.2	8.9	2.4
05:00	850 C.C.		NA	NA	NA